Prefabricated Bridge Replacement Report

Lessons Learned During Construction

Located at:

I-215 East

3760 S. & 3900 S.

Project No. IBRF-IBHF- 215-9(110)2

Constructed in 2004

Prepared for:

Utah Department of Transportation

Research Division

4501 South 2700 West

Salt Lake City, Utah 84114

Prepared by:

M. DeLoy Dye

MD2

Engineering & Development

4649 South Danna Circle

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MD2 prepared the information documented in this report and is solely responsible for its accuracy.

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June 8, 2005

Daniel Hsiao P.E.
Utah Department of Transportation
4501 South 2700 West
Salt Lake City, Utah

Re: Prefabricated Elements Bridge Replacement Research Project
Contract No. 049103 – Final Report

Dear Mr. Hsiao;

Enclosed please find twenty (20) copies of the final report for the prefabricated bridges project located on I-215 East at 3760 and 3900 South. All twenty copies are in color per your request.

If you need any additional file documents or pictures that were developed during the contract period please let me know and I will submit them to you.

I appreciated the opportunity of working on this project with you and the Research Department. I realize that the project schedule objectives were not achieved by the Contractor. The report may not have been positive to some because of the actual time required to complete the Construction. My role was to document and report. I apologize if I offended. I would like to express that the concepts used on this project could be beneficial for use on many future UDOT projects.

Sincerely;

DeLoy Dye

DeLoy Dye P.E.
MD2 Owner - Project PI

Attachments: 20 copies of report

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Introduction

UDOT'S management is looking to use concepts that allow construction projects to be completed in a more rapid time frame. Completing projects in a shorter time frame will reduce the impact to the traveling public, resulting in a user impact savings. The Prefabricated Bridge Elements project was set up to determine if rapid replacement concepts are a viable way of replacing a structure, or structural elements, in a reduced time frame. There are two major types of rapid structure replacement concepts included in this project. The first, replaces only the deck, while, the other replaces the entire structure. Because of the differences, the construction comparisons will be reported separately with their individual issues and evaluations.

Rapid Deck Replacement

The rapid deck replacement, replaces the deck while leaving the steel girders and sub-structure in place.

Rapid Bridge Replacement

The rapid bridge replacement, replaces the entire structure including the sub-structure.

Purpose

This study reviewed the comparisons between the traditional methods of performing a bridge replacement in the field compared with prefabricating the structure components offsite and then moving them to the site for installation.

The lessons learned during the construction phase of this project will address the following in detail:

Construction Comparisons
Inspection Comparisons
Traffic Comparisons
Specification Issues
Construction Time Comparisons
Conclusions

The Plan

The plan required the contractor to follow a project phasing by constructing one half of each structure at a time. Both the deck replacement and the entire bridge replacement could be worked on simultaneously during the individual phases.

Deck Replacement -The plan required the removal of the existing deck and replacing the deck with prefabricated panels. The panels were to be adjusted in elevation for overall ride quality. The joints between the panels were to be grouted together after connecting the post tensioning ducts together and prior to post tensioning. The panels were to be post tensioned in the direction parallel to the alignment of the roadway. After post tensioning, closure placements were required at each end. During the last phase, a closure placement was required down the center of the two phased sections of the deck. Sleeper slabs, approach slabs, drainage facilities, adjacent roadway replacements of both concrete and asphalt, were required at each adjacent end during each phase prior to shifting traffic and/or final completion. A polymer topcoat was required over the entire surface of the structure deck. In addition, the repainting of the steel girders was required.

Bridge Replacement - The plan required the complete removal of the entire existing bridge, one half at a time, to coincide with the project phasing. The structure was designed using a spread footing and a substructure design that allowed for the completion of the new substructure without interfering with the existing structure. Sleeper slabs, approach slabs, drainage facilities, adjacent roadway replacements of both concrete and asphalt were required at each adjacent end during each phase prior to shifting traffic and/or final completion. Applying a polymer topcoat over the entire surface of the structure deck completed this phase.

Schedule – A total of 140 calendar days were scheduled for the completion of the project. An incentive/disincentive was provided to limit the 24-hour continuous lane reduction time frame to two lanes on I-215 for a proposed 70-day period. The incentive provided $8,500 per calendar day for each day the work was completed in less than 60 days, provided that the 3 lanes were returned to continuous service without any further interruption. There was a disincentive of $8500 per calendar day if the same full time lane reduction work was not completed within the proposed 70-day time frame.

Lessons Learned Summary

Both the "Rapid Panel Replacement" and the "Rapid Bridge Replacement" provide satisfactory means for replacing the deck and the bridge respectively.

The workmanship and the quality of the prefabricated deck panels cast at the certified pre-cast yard appeared to be of a high quality. The structure replacement concept worked very well. The design provided the capability for the new substructure to be completed while leaving the existing structure in place, eliminating interruptions to the existing operations. The use of spread footings and the ability to complete the substructure greatly improved the success of the accelerated completion of the bridge replacement.

Some minor design and construction issues were encountered and will be detailed in this report along with some specification recommendations.

The perception of accomplishing the work in a shorter time period than the traditional method was not totally realized. The main reason the anticipated timesavings were not achieved on the project was because the Contractors objectives differed from UDOT'S. UDOT wanted the contractor to provide the resources necessary to complete the project in a prescribed time. The Contractor leveled the resources to maintain a quality work force and provided just enough equipment to optimize costs. Equipment and crews were not working simultaneously on all bridge segments that were available. It would have required multiple crews and additional equipment to meet UDOT'S objectives.

The project phasing nearly doubled the number of different activities. The number of activities required to complete the project was a definite impact to not realizing a perceived shorter construction period. The actual time required to complete the work, during the 70-day, two-lane traffic limitation exceeded expectations.

There are several additional reasons why the shorter construction time was not realized. First, the project was delayed at the time of award. This caused some of the pre-cast elements and the on site project work activities to be performed simultaneously. Second, the time incentive set up in the contract did not entice the contractor to allocate the resources needed to work on multiple activities simultaneously. The contractor opted not to allocate the resources needed to shorten the construction period. Finally, the project included two different types of experimental concepts, one being a deck replacement, the other a bridge replacement. The two different concepts did not allow any continuity to be developed. These new concepts required new individual construction techniques and learning curves. The timing for completing many of the roadway items did not coincide with the placement of the prefabricated bridge elements.

Traffic impacts anticipated on the project were estimated by a study conducted by the University of Utah. Recommendations were made that construction be performed during off peak traffic times in order to minimize the impact on traffic. The plan was to reduce the normal three lanes down to two during the structure replacement period of the contract. Traffic was observed throughout the construction period. At times, traffic was reduced to a single lane. The single lane was required to provide access to the work zone. This would not have been necessary had the traffic been shifted to provide continuous two way traffic in the opposite direction of travel as is traditionally done. During the period when two lanes remained opened, there were no noticeable delays, even during peak traffic periods. Major delays were only encountered during peak traffic times when the traffic lanes were reduced to a single lane through the construction zone. If the project had been designed with traditional cross over, no significant delay would have been encountered.

It is nearly impossible to determine the increased cost associated with the concept of prefabricated elements on this project. One should not assume that all increases in cost are associated with the prefabricated concept. Usually, one can expect an increase in cost when a new concept is attempted for the first time. Additionally, traffic phasing could have played a role in the additional cost of the project. An expected increased cost of the prefabricated bridge concept could be estimated near 20% when compared to the cost of traditional deck replacement. However, the increased cost could be offset by a user cost savings in the form of a reduction of time taken to complete a project. More details on project costs can be found under lessons learned by topic.

The long-term performance of these methods is yet to be determined. The individual pre-cast deck panels appeared to be of a higher quality, although the post tensioning required time to accomplish. The post tensioning appeared to connect the panel together in a quality manner. The reconnecting of the Nelson Studs to the existing beams should be addressed by specification and evaluated over time.

Lessons Learned by Topic

Minimize roadway items

The project had several roadway items included in the project. The lane restrictions were implemented long before the prefabricated elements were ready for installation. This was done to complete the roadway items. To obtain the optimum benefit of a rapid structure replacement; the critical path needs to run through the structure and not through the roadway items.

Provide adequate lead-time

The project was delayed at the time of award, which impacted the dates that the contract provided for lane restriction. The lane restrictions were implemented as allowed by the contract. With adequate lead-time, the prefabricated sections could be completed before any impact on the roadway occurred. The prefabricated structure was being constructed in the same timeframe that the roadway items were performed. The workforce was working on the prefabricated elements, resulting in minimal work being done on the roadway items during the two-lane closure timeframe.

Phase to minimize the number activities

Regardless of the procedure used to replace a structure, traffic impacts are to be expected. Traffic needs to be handled in the best method possible. If traffic must be maintained on the system, it will increase the time to replace the structure. When a structure is divided into two sections; it nearly doubles the required activities to complete the project. Increased activities will increase the cost and require a larger workforce.

Complete the Entire Structure

Reducing the three traffic lanes to two lanes and leaving the traffic on half of the structure required the structure to be constructed one half at a time. The dividing of the structure resulted in a connection of the post tensioning in the middle of the prefabricated bridge. These connections required additional forming and could cause potential performance problems. The additional block-out required to accommodate these connections could impact the long-term performance of the structure.

Cost

The Designer, during an interview, said that the structure items for this project were increased by 30%. After the bids were opened the lowest bid exceeded the engineers estimate by 28%. Many projects involving Structural Steel have overrun the estimate by 30% due to recent rapid increases in steel costs. There is no way to determine how much of the increased cost should be attributed to the first time unknown risk. There is also a cost associated with the learning of new concepts. Additional cost resulted due to the post tensioning of the prefabricated deck.

Incentives

The contractor provided a standard crew to complete the project. During a large portion of the contract, the contractor's crew was working on roadway items or working on the prefabricated elements. This was being done during the same time frame when traffic was being impacted. The time incentive set up in the contract did not entice the contractor to allocate the resources needed to shorten the construction period. An incentive needs to and rewarding enough to entice the contractor to accomplish the intended goal. The intent of an accelerated completion incentive benefit should reward the contractor for the additional effort and cost required to better manage the schedule and provide the resources needed to accomplish the intended time goal.

(A) Prefabricated Deck Replacement

Construction Comparisons (Deck replacement)

Traditional Construction Activities

- Removal of existing deck (2 days)
- Form deck and place reinforcing steel (20 days)
- Deck placement (1 day placement 21 days cure)

Total of 44 days

Construction activities required for (Prefabricated Deck replacement)

The following activities were involved with the pre-cast deck panel application:

	Theoretical	Actual
• Prefabricate panels (Completed prior)	N/A	N/A
• Removal of existing deck	(2 days)	(6 days)
• Removal of the nelson studs	(1 day)	(4 days)
• Set pre-cast deck panels	(1 day)	(2 days)(1 set crane)
• Establish panel grades	(1 day)	(1.5 days)
• Connect post tensioning ducts	(1 day)*	(not provided)
• Grouting panels together (cure)	(2 days)*	(1 day)
• String post tensioning cables	(2 days)*	(1 day)
• Perform post tensioning	(2 days)*	(1.5days)
• Grout posts tensioning ducts (cure)	(2 days)*	(1 day) (Cure?)
• Replacement of the nelson studs	(3 days)	(3.5 Days)
• Form (haunches, end & center closures)	(2 days)	(? days)
• Closure placements (cure)	(1 + 7 cure)	(3 days) (cure?)
• Grout block-outs	(1 days)	(1.5 days)
Total	28 days	(27 days) (cure?)

(Mean of 28 days)(5-7 days related to post tensioning)*

Prefabricated Panels

The prefabricated panels required additional forming details including, block-out for the nelson studs, and placement of the post tensioning ducts, vertical adjustment screws, and pick point lifting devices. These obstacles also caused interference with concrete finishing. (See Figure # 1)

Figure # 1 Block-outs v. adjustment screws, lifting devices, & tensioning ducts

Placement of pre-cast panels

If the horizontal alignment is properly set with the initial panel no difficulty should be experienced in placing the consecutive panels. It is important to align the first panel so the Nelson Stud Block-outs maintain alignment with the beam flange across the entire length of the structure. There were no issues with the placement of the pre-cast panels. All of the panels in phase one of a single deck were placed in one, 12-hour day. The placement of the panels is where time can be saved over traditional forming and placing methods.

Figure # 2 Panel delivery & pick points

Figure # 3 Panel placement & alignment

Establish Panel Grades

The adjustment screws work very well for establishing the desired vertical grade. Each of the deck panels rested on four or five different beams. There were three different leveling screws in each panel for each beam. When concrete is place in its plastic state, the load is naturally distributed uniformly over each beam. The load of the rigid panel needs to be uniformly applied across each beam to avoid over-loading or under-loading of an individual beam. In addition a concentrated load on one leveling screw could damage the panel near the leveling screw. The requirement of a uniform load, at each adjustment screw location, would eliminate this concern. UDOT'S Designer feels that the affects of non uniform loading of the leveling screws needs to be addressed in Design and in the Specifications describing the panel placement procedure.

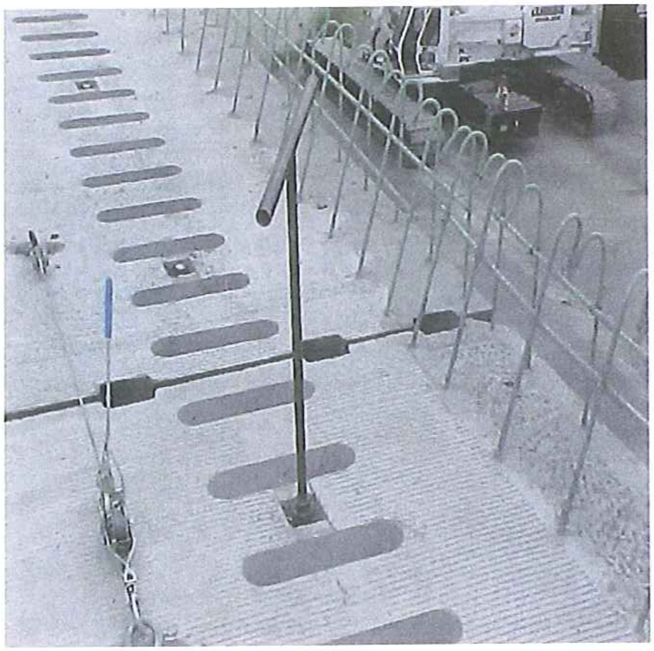

Figure # 4 Vertical adjustment

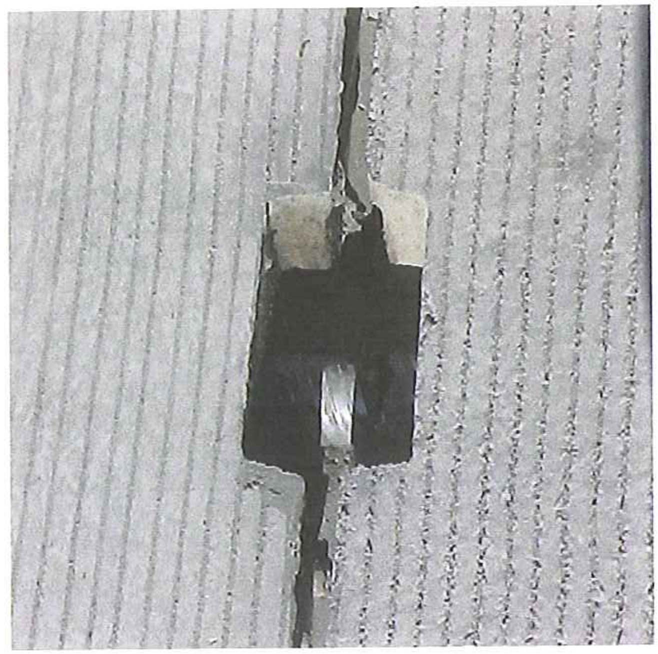

Figure # 5 Tensioning ducks

Connecting of the posts tensioning ducts

Every joint had tensioning duct that had to be connected together at each of the eleven different joints for all the different deck sections.

Grouting of panels

Each joint between the eleven different panels of the different deck sections had to be grouted together prior to placing the post tensioning cables.

Stringing of post tension cables

Five strands of post tension cable were strung as required in each of the post tensioning ducts.

Post tensioning of panels

Post tensioning was performed for every tensioning bank, at each of the four different bridge phases.

Grouting of post tensioning cables

After the post tensioning had been completed, each of the duct banks had to be grouted. This again, was required, on all four sections of each bridge.

Placement of Nelson Studs

Once the deck had been secured together, the Nelson Studs were installed.

Grouting of block-outs

The filling of the Nelson Stud block-outs with non-shrink grout proved to be a problem. The grout material seeped through the haunch forms. The product shrank and some of the leveling screw and pick point block-outs popped out soon after opening to traffic.

Inspection Comparisons

Traditional Inspections Eliminated (Pre-cast Deck Replacement)

There were no significant eliminations in inspections. The placements are spread out due to the additional number of individual panel placements.

Additional Construction Inspections Required (Pre-cast Deck Replacement)

Inspection of installation of post tensioning ducts, Nelson Stud Block-outs
Consolidation of concrete around block-outs
Cleaning of the tops of the existing girders
Inspection of cable installation and post tensioning activities
Inspection of installation and testing of the Nelson Studs

Problems encountered (deck replacement)

Removal of the existing deck

Problem - A close inspection of the steel girders revealed that some damage occurred during the deck removal operation. Damage was not in the cross diaphragms. Some were bent while in others the bolts sheered off at the cross point.

Solution - More detailed information in the specification defining methods for removal that will prevent damage from occurring to the steel girders during the deck removal process. A designed deck removal plan may also be necessary for complicated bridges.

The Bonding of the Nelson Studs

Problem - Obtaining a good bond between the beam and the Nelson Studs proved difficult. This could have resulted from the lack of cleaning of the top of the flange or from insufficient energy to fully infuse the studs to the beam.

Solution - During phase two, the beams were cleaned better and a higher energy source was used. These changes improved the bonding quality of the Nelson Studs in phase two. Improve specification or plans to require cleaning requirements and define minimum energy for the stub welder.

Failures in the non-shrink grout

Problem – Non-shrink grout was used to fill the Nelson Stud Block-outs. Shrinkage cracks occurred in several of the block-outs. In some cases, a portion of the grout came out of the small leveling and pick point block-outs. The Contractor placed some of the non-shrink grout in lifts and some were placed full depth. Regardless of the placement procedure used the results were poor. UDOT'S Designer felt improper material was used. UDOT and the Contractor relied on the grout supplier to supply an appropriate material for the application. The Grout supplier used a very expensive product. After the product failed a technical representative of the grout supplier stated to the UDOT Designer that the material used was not appropriate for the application. The Representative told the Designer that they had a much cheaper product for this type of application.

Solution - Do not rely on a salesperson to select products. The material should be product that has been tested for non-shrink characteristics as well as strength and durability qualities. The Resident Engineer and the Designer agreed to allow the use of conventional deck mix in the block-out during phase two. This conventional deck mix material appears to be performing very well. (See Figure #6 and #7 for comparisons)

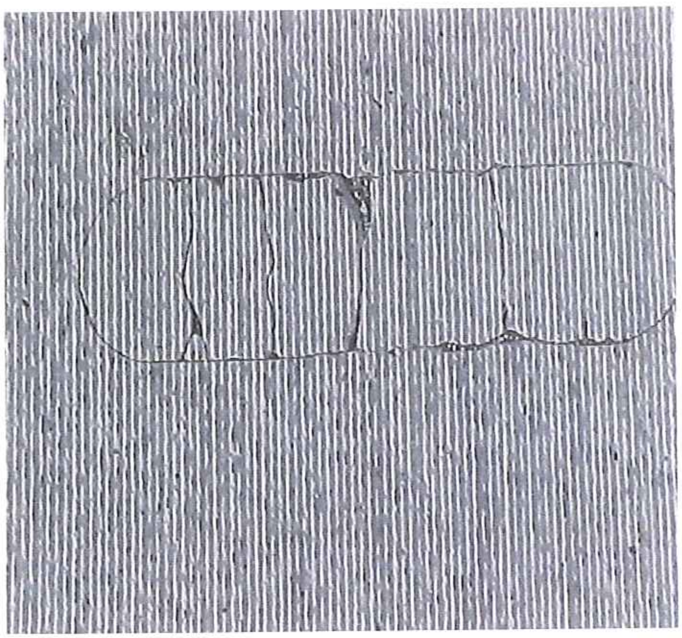

Figure # 6 Non- Shrink Grout

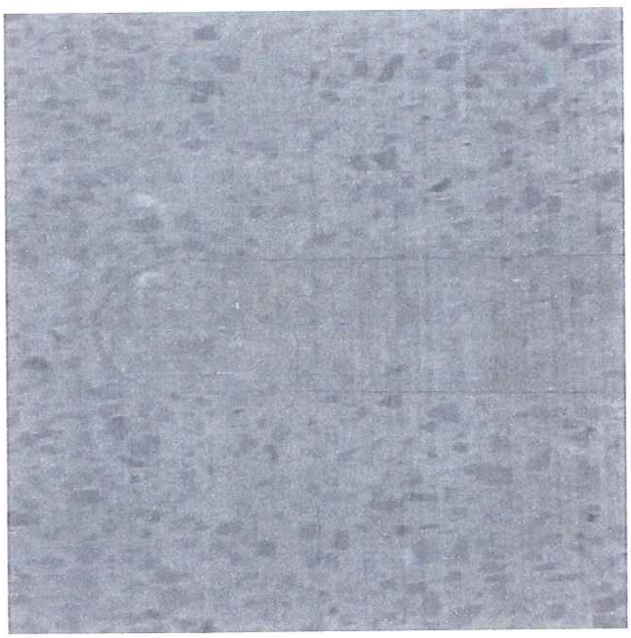

Figure # 7 Conventional Concrete

Specification Issues (deck replacement)

Consider writing specifications for the following:

Uniform support on the deck adjustment screws
Testing of Nelson Studs
Deck removal requirements
Cleaning of girders
Grouting (non-shrink)
    Grout for ducts
    Grout for camber strips
    Grout for block-outs

Conclusion

The use of prefabricated bridge deck panel elements provided a viable method for the rapid replacement of a deck.

Advantages of Rapid Replacement for "Deck Replacement"

- The quality of the pre-cast panels can be closely controlled.

- A reduce complete time can be achieved. Needed is a well-planned schedule that the contractor mutually agrees too. The time saving can be realized when using prefabricated deck panels mainly due to the elimination of the forming and cure time required for a cast in place deck.

- The use of post tensioning on the deck may increase the life expectancy, but it increases the amount of time and cost required to replace the deck. Elimination of post tensioning could further reduce the time required and the cost of replacement. Caution should be used in eliminating the posts tensioning because it could improve the long-term performance of the numerous joints required in this replacement concept.

Disadvantage of Rapid Replacement for "Deck Replacement"

- Increased Cost

- Long term performance not proven

(B) Prefabricated Bridge Replacement

Construction Comparisons (Bridge Replacement)

The ability to construct the substructure portion of the bridge, without disruption to traffic, was a real benefit to replacing the superstructure of the bridge in a shorter time frame. The time savings as a result of the substructure being in place would have been realized regardless of the method of replacement used. Having the completed substructure available made it possible to remove half of the existing structure not being used by traffic and allowed for the placement of the prefabricated bridge elements to be place for one phase in just two days. The alignment of the bridge elements, stringing post tensioning rods, post tensioning, grouting, backfilling back walls, constructing sleeper and approach slabs, and other roadway items required more time to complete than the actual installation of the bridge. Had the entire bridge been available it would have required only a few days more to complete the entire bride than was required to complete one half of the Bridge. When placing one half of the bridge at a time, the workspace is limited and causes time delays in completing individual tasks by reducing equipment efficiency and equipment relocation time. Then the same activities have to be repeated during a 2nd phase.

Traditional Cast-in-place Activities

The prefabricated bridge was constructed in the temporary location in the same manner as is traditionally done by the cast-in-place method. There was no elimination of activities from the traditional method, because the bridge is constructed the same as the traditional method only in a temporary location. The benefit was; the precast structure could be completed including the cure period, prior to the disruption of traffic.

Estimated Time for Traditional Bridge Replacement (assume substructure in place)

Removal of existing bridge	(2 days)
Installation of steel girders	(4 days)
Form deck	(7 days)
Place Reinforcing Steel	(3 days)
Place Concrete	(1 day)
Cure period	(28 days) UDOT'S Specification
Total	**(45 days)**

Additional Activities Required for Prefabricated Bridge Replacement

Temporary foundation for prefabricated bridge
Additional forming for post tensioning block-outs and construction joints

Permanent Site Activities

	PI 'S	Project Record
Removal of existing bridge	(2 days)	3 days

Installation of bridge segments	(2 days) (traffic impact)	2 days
Installation of Post tensioning bar	(4 days) (per phase)	2 days
Post tensioning of bars	(3 days)	4 days
Sealing of post tensioning bars	(1 day)	2 days
Grouting of post tensioning bars & Block-outs	(2 days)	N/A
Total	**15 Days**	**13 + 2**

Days recorded for activities involved with traffic impacts.

Associated Activities Required During Traffic Shifts (per phase)

	PI 'S	Project Record
Backfilling of abutments (about 6 feet)	(4 days)	N/A
Construction of rag wall to accommodate backfilling (included with BF)		
Placement of sleeper slab	(2 days)	3 days
Placement of approach slab	(2 days)	4 days
Placement of drainage pipe	(2 days)	N/A
Placement of inlet structures	(2 days)	N/A
Placement of concrete pavement (curing time)	(10 days)	4 days + cure
Placement of asphalt pavement	(1 day)	1 day
Placement of cast in-place barrier	(2 days)	N/A
Total	**(25 Days)**	

Figure # 8 Temp. Footing for Prefab.

Figure # 9 Block-outs, ducts, & divider

Foundation for Prefabricated Bridge

It was necessary to construct a temporary footing at the prefabrication site for the prefabricated bridge. The footing needed to have the capability to support the prefabricated bridge. (See Figure # 8). The Contractor did not perform an adequate footing design review. The first footing constructed at the temporary prefabrication site was inadequate to support the prefabricated bridge. Settling occurred once the structural steel was placed on the footing. The Contractor had to remove the structural steel and increase the size of the footings. The project was delayed due to the settling of the initial footing.

On future projects, UDOT wants to consider providing a design for all elements required; including the temporary footing; needed to complete the project.

Additional Forming

Additional forming was required for the post tensioning block-outs and the joints along the longitudinal bridge element. A great amount of detailed forming was involved. There were so many obstacles near the surface of the deck. Because of these interferences the use of a Bidwell Finishing Machine was not used for placing the concrete. The deck was finished by hand screeding methods. (See figure # 9, 10, and 11)

Traditional Inspections Eliminated (Bridge Replacement)

No traditional inspections were eliminated since the bridge had to be constructed in its temporary location by traditional methods.

Additional Construction Inspections Required (Bridge Replacement)

Additional inspections are necessary for the prefabricated bridge. Even with the builder being responsible for the temporary footing additional reviews need to be conducted to determine the potential impacts to the structure if the temporary footing is inadequate. Inspections are required on all details involved with the additional forming and the installation of the post tensioning ducts. During the installation of the bridge elements inspection of how the element seat together and how they set on the footing need to be evaluated. Inspections of all the post tensioning need to be perform.

Specification Issues (Bridge Replacement)

On future projects, specifications for the following topics should be considered:

Foundation for Temporary Bridge (assign risk)
Epoxy along segment joints (consider injecting)
Grouting materials (non-shrink)
Sealing of post-tensioning bars
Grouting (placement)
Grout compared to deck concrete (Compatibility)

Long Term Performance

The long-term performance of the longitudinal joints and the post-tensioning block-outs, along each bridge segment needs to be monitored over time.

Figure # 10 Deck Forming Details

Figure # 11 Prefabricated Deck Placement

Problems Encountered

Structural Capability of the Temporary Footing

Problem: After the girders had been set onto the temporary footing the weight of the girders caused the footing to settle. All of the beams had to be removed and the footing had to be enlarged in order to support the temporary bridge in a same position as it would be in its final position.

Solution: Identify in the contract that the Contractor needs to design a temporary footing adequate to support the bridge identical to its final designed position.

Uniform Bearing Load between the Substructure and the Superstructure

Problem: After the prefabricated bridge had been set on the bearing seat, the bottom backwall section of the prefabricated bridge did not sit flush on the bearing pad. A rotation in the backwall occurred during the casting of the deck at the temporary site. The dead load deflection of the deck caused the rotation in the backwall. This occurred because the backwall portion of the bridge had been placed prior to the placement of the deck. This issue had been anticipated and discussed prior to placing of any of the concrete placements. Pictures were taken to show that some rotation had occurred while the structure was still sitting on the temporary footing. The loading of the deck may not have overcome all of the stresses in the bridge with the massive backwalls already in place. Addition rotation may have occurred due to the equalizing of the stresses during the transporting of the individual bridge segments from the temporary prefabricated location to the final structure location.

Solution: Sequence the placement of the concrete. Load the deck prior to placing the concrete into the backwall.

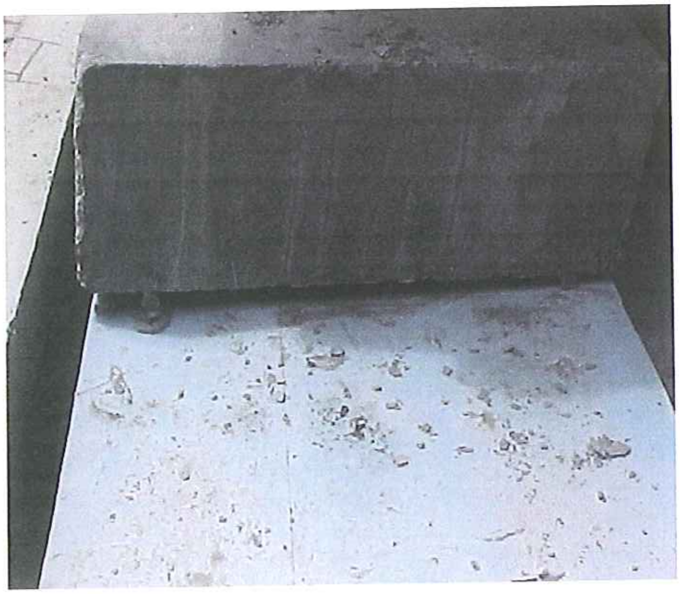

Figure # 12 Bridge Bearing

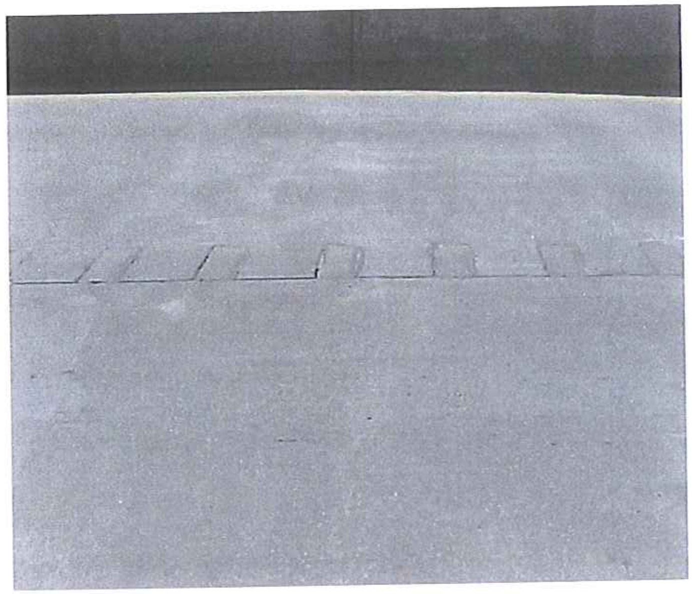

Figure # 13 prefabricated deck surface

Sealing of the Longitudinal Joints

Problem: The contract specified that an epoxy material to be placed on the longitudinal joints of the bridge elements. The epoxy material was placed on the joints during phase one as the bridge elements were set into place prior to the post tensioning of the bridge elements. The epoxy material hardened prior to the posts tensioning. The hardened material was not uniform along the joint. During the post tensioning operations the non-uniform surface along the joint caused Spalding of the deck adjacent to the joint. The epoxy sealer was not placed on the elements during subsequent placements.

Solution: Consider using a pliable material for sealing the joints or inject the epoxy material after the post tensioning has been completed.

Conclusion (Rapid Bridge Replacement)

Advantages of Rapid Bridge Replacement

The concept of prefabricated bridge elements to provide rapid bridge replacement has real potential to reduce the time required to replace a bridge. It has a greater potential for reducing time, as shown on this project, if the sub-structure is completed while leaving the existing structure in place.

Additional time can be saved by completing an entire bridge rather than a portion of the bridge. One post tensioning setup involving three or four days can be eliminated for each phase. It also allows for the completion of many of the approach activities in one operation. Time required to complete these activities is reduced because it allows for the efficient operation of equipment and reduces the amount of hand work.

With adequate lead-time, the pre-cast elements would be available before the traffic is impacted. If bridge replacement is the main focus of the project, the project could be completed in a reduced time frame. Constructing the substructure, while leaving the exiting bridge in operation, greatly reduces the time required for completion. The optimum benefit could be realized if the substructure was in place and traffic could be removed (detoured) while the prefabricated bridge is installed.

Disadvantages of Rapid Bridge Replacement

Cost
Specialized Equipment
Design for individual bridge elements
Unknown long-term performance
Specific geometry issues associated with individual project location can have large impacts on cost and time required.

Lessons learned UDOT Designer's Perspective

- Maximize construction tolerance.
- Fully flush out all details.
- Minor items/statements on plans can add significant cost and time.
- I.E. the remove stud item stated, "grind smooth". Not a trivial task for 18,000+ studs.
- Double or triple design time for rapid construction to allow us to fully evaluate the consequences of all decisions.
- Don't rely on the contractor to "engineer". Dictate exactly how the job is to be done.

PI'S Recommendation

- Have the contractor on board with understanding of rapid schedule goal.
- Have all prefabricated elements available prior to traffic interruption.
- Be sure the roadway items, that influence traffic, do not override the rapid replacement benefit on the project.
- Remove traffic from the entire bridge to obtain maximum time savings, benefits from the elimination of joints between phase elements and duplication of activities on the same bridge

- Consider the impact of live load vibration impacts on closure pours.
- Evaluate potential complications of precast location.
- Assign risk of precast foundation responsibilities.

Construction Time Comparisons

A total of 140 calendar days were scheduled for the completion of the project. An incentive/disincentive was provided to limit the 24-hour continuous lane reduction time frame to two lanes on I-215 for a proposed 70-day period. The incentive provided $8,500 per calendar day for each day the work was completed in less than 60 days, provided that 3 lanes were returned to continuous service without further interruption. There was a disincentive of $8,500 per calendar day if the same full-time lane reduction work was not completed within the 70-day time frame.

The two different types of rapid replacement methods, the numerous number of roadway items, along with phasing, increased the number of activities involved with the project. The time to complete all the activities, along with the resources provided by the contractor, resulted in no shortened project time. There are several reasons why the shorter construction time was not realized. First, the project was delayed at the time of award. This caused some of the pre-cast elements and the on site project work activities to be performed simultaneously. Second, the time incentive set up in the contract was not sufficient to entice the contractor to allocate the necessary resources needed to work on multiple activities simultaneously. Also the project included two different types of experimental concepts, one being a deck replacement the other being a bridge replacement. The two different concepts did not allow for any continuity. These new concepts required individual construction techniques and learning curves. Lastly, the timing for completing many of the roadway items did not coincide with the placement of the prefabricated bridge elements.

Time estimated by designer to perform bridge work	35 days (per phase)
Contractor baseline schedule to perform bridge work	35 days (per phase)
Actual time to perform bridge work	50 days (per phase)
Traditional Construction (superstructure only)	50 days (per phase)

Traffic Comparisons

From a construction perspective, the first option would be to remove all traffic and perform the construction. Normally, the traffic would be directed onto one side of the freeway, by the use of crossovers, maintaining two continual operating lanes. This process provides the contractor the opportunity to construct the bridge where there is no traffic flow. Upon completion of the initial bridge, the traffic should be reversed to allow the completion of the remaining companion bridge.

The University of Utah performed a traffic analysis throughout the project. Their results indicated that there would be some impact to the project if handled in the traditional method. In the "Conclusions and the Recommendations" portion of their report, it was recommended that the work be performed during off-peak traffic periods. (See Attachment A pages 43 and 44 of their report)

UDOT determined that using crossover was not an option for this project. This decision greatly complicated the design and construction of the project. Not being able to complete an entire bridge nearly doubled the resources required. The additional time required to complete the construction gave the perception that the method used did not accelerate the project. Regardless of the construction method used, the construction of half the deck or bridge at separate times nearly doubled project time.

The plan was to reduce the normal three through traffic lanes in each direction to two lanes during the period of the bridge replacement. Traffic was observed throughout the duration of construction. Due to project phasing, there were times when the traffic lanes were reduced to a single lane in order to provide access into the work zone and improve work zone safety. During times when two traffic lanes were maintained, there was no significant impact to the traffic flows. When only one lane was available, only minor impacts were noted during non-peak periods but, significant impacts were noted, during the peak periods. (Different than was anticipated in attached University of Utah Study)

Traffic Lesson Learned

Addressing what to do with traffic is necessary, regardless of the type of construction method used for the reconstruction. If a total closure to traffic is possible, and used, time for completion can be greatly reduced, regardless of the method used to complete the reconstruction. An earlier completion can be achieved by providing the builder a complete unit, instead of dividing the single bridge into two units. This will reduce the number of construction activities by half and will enable the overall project timeframe to be reduced.

Cross traffic and pedestrian traffic may be impacted for a longer duration even if the overall time for replacement is shortened. Normally cross traffic and pedestrian traffic can be maintained with minor interruptions during tradition construction methods.

Traffic Time Impact Comparisons

The intent of a rapid bridge replacement is to reduce the amount of time that traffic is disrupted. Major time savings can be realized if the new substructure can be completed without interfering with the traffic. The time required to construct the substructure is greatly influenced by the foundation treatment required. The use of spread footings for the foundation treatment allows for most of the substructure to be completed without disruption to the traffic. The anchoring of the superstructure to the sub-structure was modified on this project to improve the potential for rapid installation of the superstructure. The ability to complete the substructure without interfering with traffic greatly improves the success for rapid bridge replacement.

The actual time require to place the superstructure can be greatly reduced using prefabricated bridge elements. The main time benefit obtained from prefabricated elements is due to the elimination of time required for deck forming and the cure period, when compared with the traditional cast-in-place construction method. Time saving could also be achieved for traditional cast-in-place placement method if the use of high early mixes and strength requirements could be used to determine time frames for opening to traffic.

Another major impact for rapid bridge replacement is the ability to complete the entire bridge in one phase. If the bridge is completed in phases, all activities must be repeated for each phase, increasing the replacement time. It also influences the productivity due to the reduced workspace, which does not allow efficient use of all equipment, increasing the need for more handwork.

The benefit of completing the entire bridge in one phase is summarized for clarification. These benefits are based on the assumption that the substructure is in place prior to traffic impacts. Following are estimations of the time needed to complete the superstructure work.

	Phase one	Phase Two	Complete bridge
Placement of steel beams	4 days	4 days	7 days
Forming of deck	10 days	10 days	15 days
Place reinforcing steel	5 days	5 days	7 days
Place concrete deck	1 day	1 day	1 day
Cure deck	28 days	28 days	28 days
Total	48 days	48 days	58 days

Time frame for rapid bridge superstructure replacement:

Install bridge elements	2 days	2 days	2 days
Install post-tensioning	2 days	2 days	3 days
Post tensioning	4 days	4 days	5 days
Sealing of post-tensioning	2 days	2 days	3 days
Filling and curing of block-outs	2 days	2 days	2 days
Total	12 days	12 days	15 days

If the entire bridge is constructed in a single phase, completion time can be reduced by 38 days compared with the two-phase time frame when using traditional construction.

If the entire bridge is constructed in a single phase, completion time can be reduced by 9 days compared with the two-phase time frame when using rapid replacement procedures.

If the intent is to reduce time impacts on projects, careful consideration needs to be given to the benefit that can be achieved by constructing the entire structure as one unit. Whenever possible the traffic should be removed from the bridge to allow for complete construction of the entire bridge.

Conclusion (Time Benefit):

There is a time savings with the prefabricated deck replacement and prefabricated bridge replacement, however the time savings from a Prefabricated Bridge replacement can exceed the time saving from that received from replacing a Prefabricated Deck replacement. There is a real time saving benefit in replacing an entire bridge with prefabricated bridge elements provided the substructure is completed while leaving the traffic undisturbed. The Quality of the prefabricated joints can be improved if the entire structure can be completed in a single phase. If these conditions are available, then prefabricated bridge elements could be an excellent method for rapid bridge replacement.

Ref: Appendix A
University of Utah study
See Conclusions page 43 (attached)
See Recommendations page 44 (attached)

Appendix B
Letter from I-215 west project
Estimated Construction times

Photo Log – Pre-Cast Deck Panel Field Installation

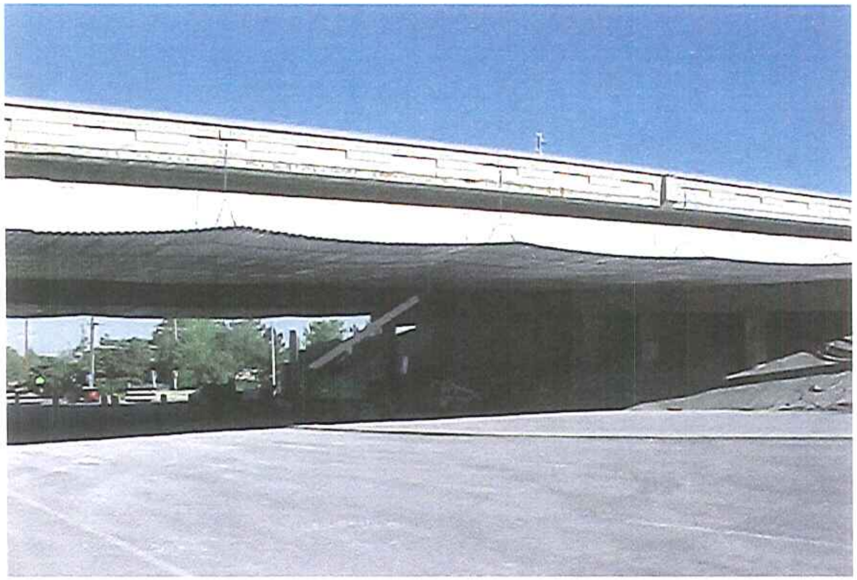

Figure # 24 Structural steel cleaning and painting

Figure # 25 Steel after deck a & nelson stud removal

Figure # 26 Top flange condition

Figure # 27 Cleaning sample by grinding

Photo Log – Pre-Cast Deck Panel Field Installation

Figure # 28 Deck panel delivery & Pick points

Figure # 29 Deck panel lifted onto beams

Figure # 30 Deck panel placement quality of installation

Figure #31 Deck panel & Post tensioning ducts

Photo Log – Pre-Cast Deck Panel Field Installation

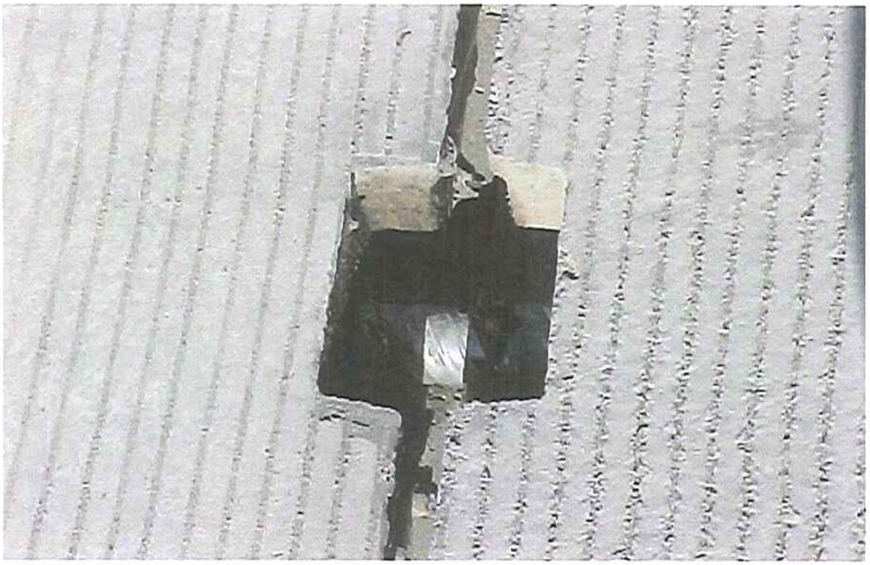

Figure # 32 Post tensioning duct connection & block-out

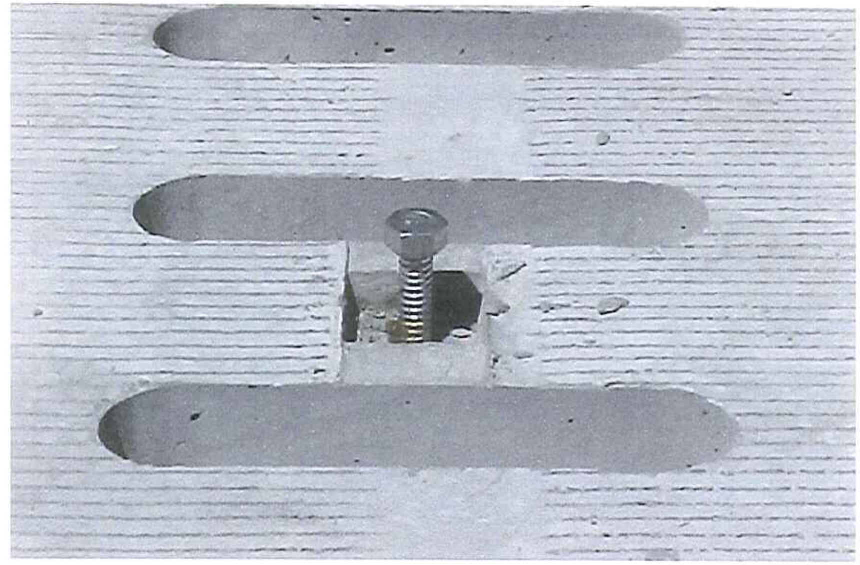

Figure # 33 Vertical adjustment screw

Figure # 34 Vertical adjustment screw

Figure #35 Filling of perpendicular joint between panels

Photo Log – Pre-Cast Deck Panel Field Installation

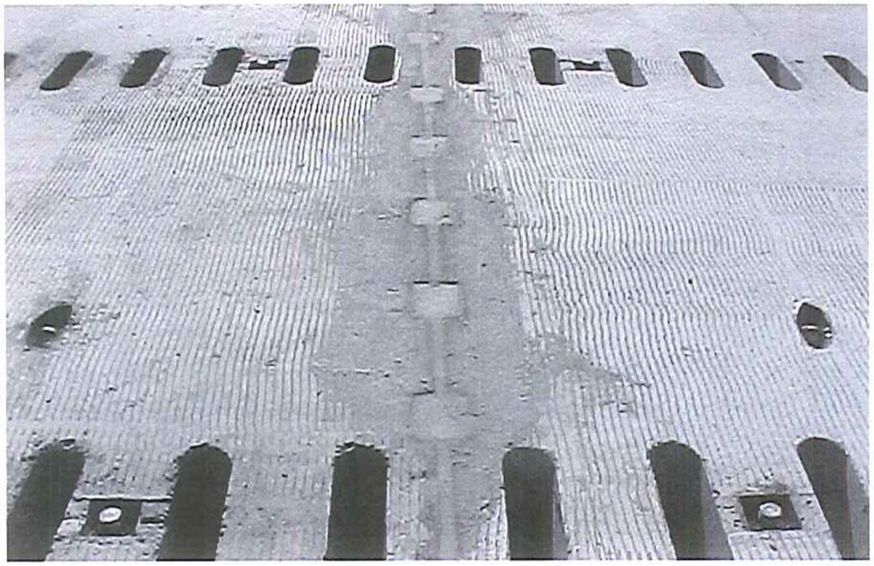

Figure # 36 Filled perpendicular joints between panels

Figure # 37 Deck panels adjusted and connected

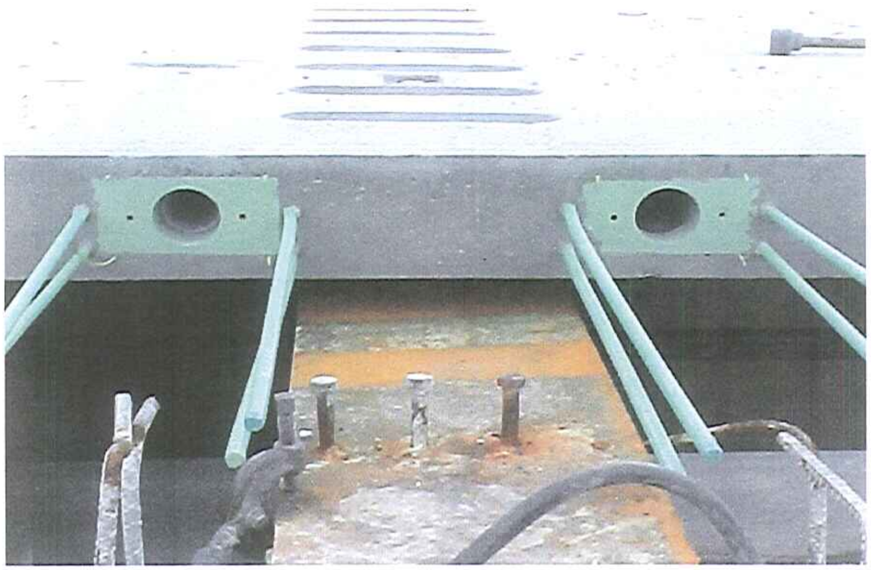

Figure # 38 Post tensioning ducts ready for cable

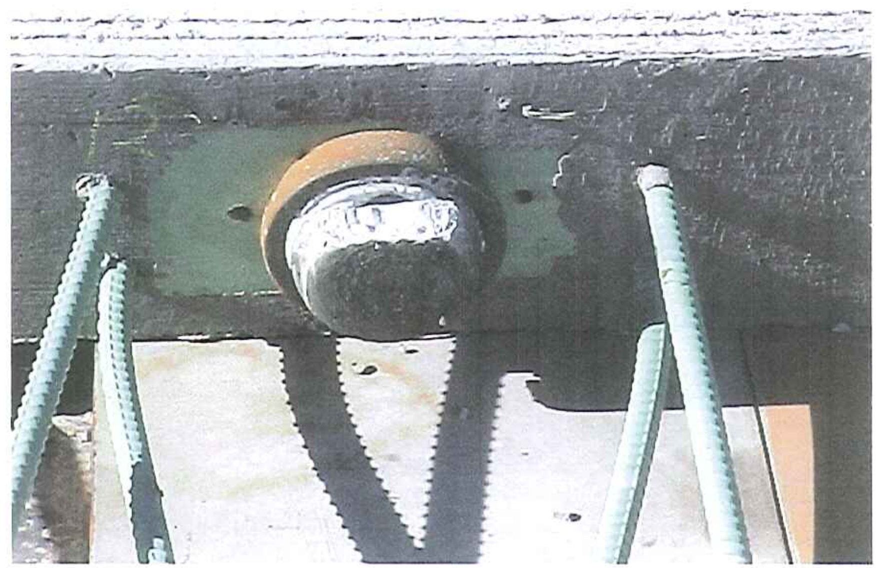

Figure # 39 Completed post tension duct

Photo Log – Pre-Cast Deck Panel Field Installation

Figure # 40 Post tensioning duck grouting tubes

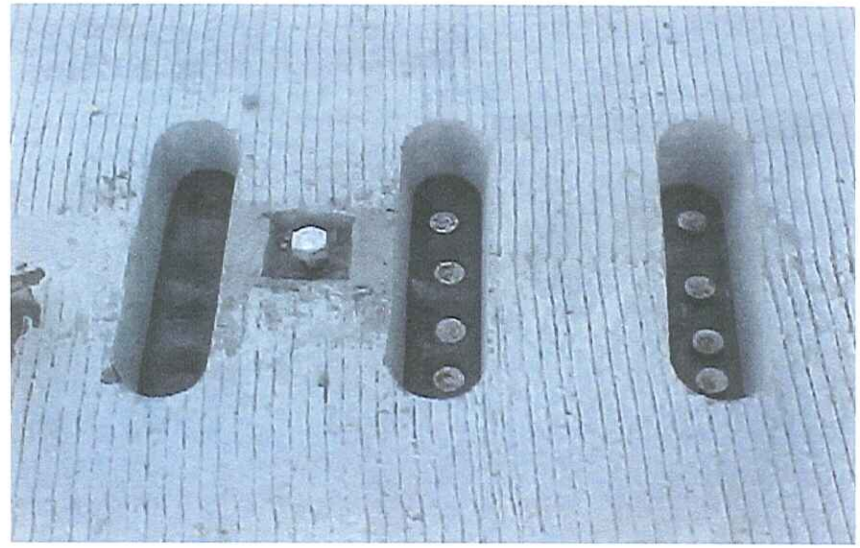

Figure # 41Nelson stud installation

Figure # 42 Filling of nelson stud block-outs

Figure # 43 Consolidation of grout in flange and block-outs

Photo Log – Pre-Cast Deck Panel Field Installation

Figure # 44 Forming for the flange

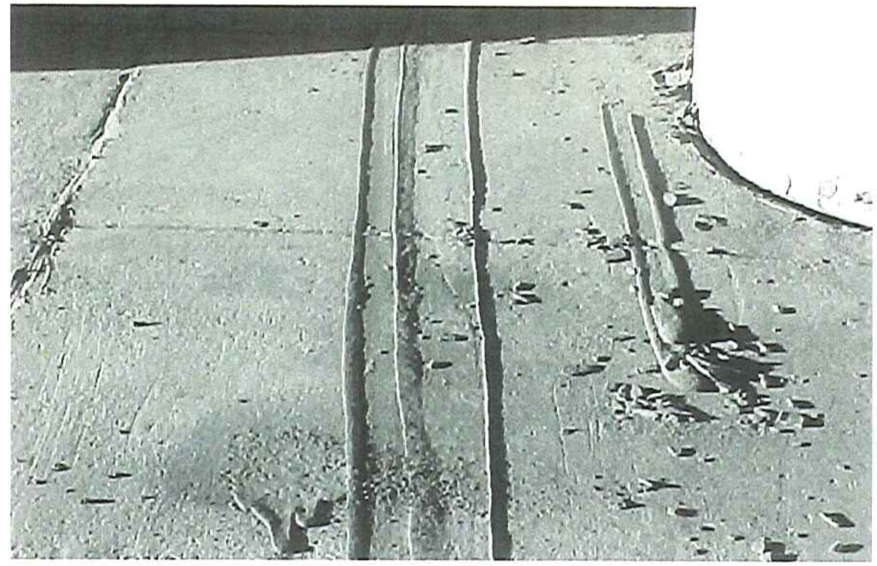

Figure # 45 Grout that leaked onto slope protection

Figure # 46 Partially stripped flange

Figure # 47 Failed non-shrink grout plug

Photo Log – Pre-Cast Deck Panel Field Installation

Figure # 48 Deck end closure detail

Figure # 49 Sleeper slab & Approach slab

Figure # 50 Approach slab and needed roadway tie

Figure # 51 Pavement Connection & Future asphalt shoulder

Photo Log – Pre-Cast Deck Panel Field Installation

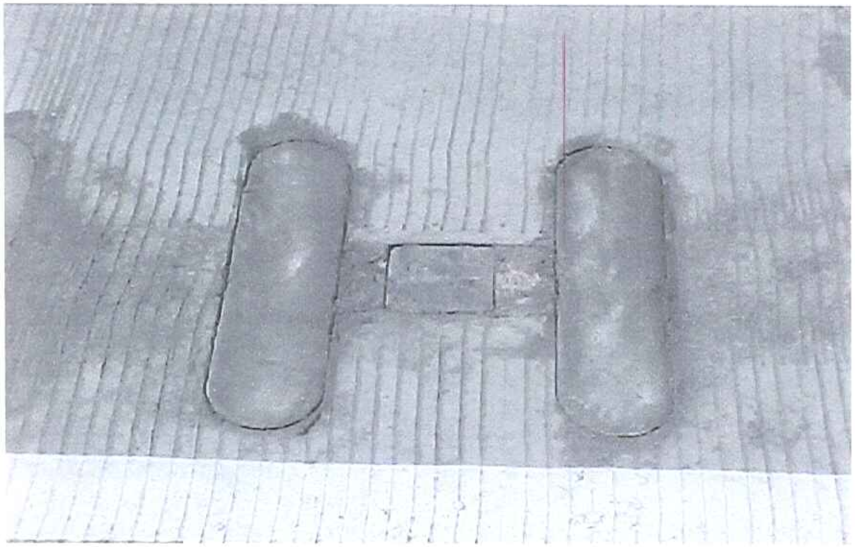

Figure # 52 Non- shrink grout

Figure # 53 Test non-shrink grout with aggregate blend

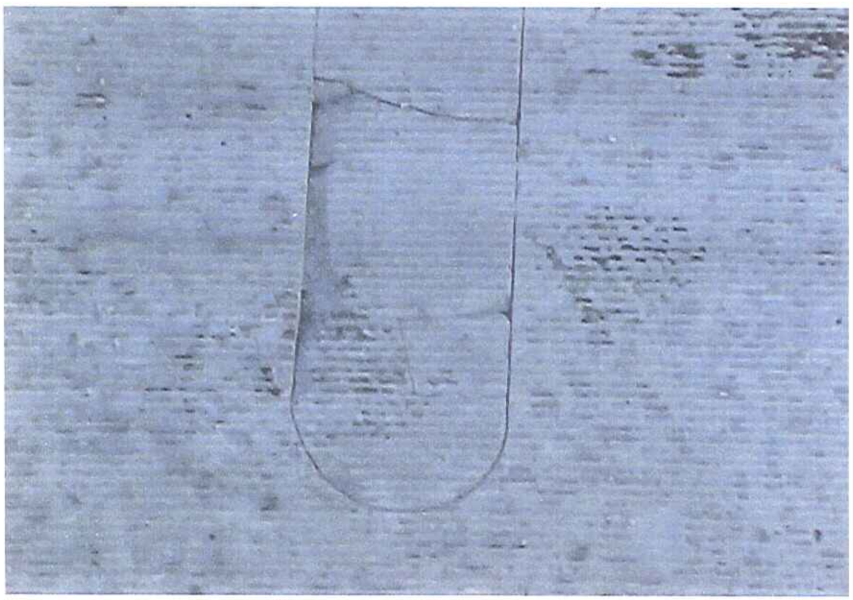

Figure # 54 Cracks in non-shrink grout after grinding

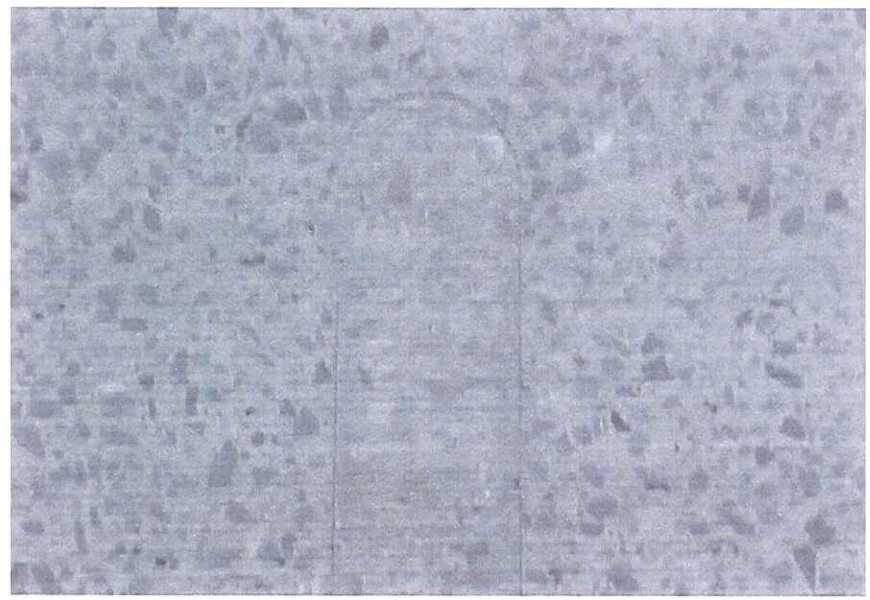

Figure # 55 Conventional concrete block-out patch after grinding

Photo Log – Pre-Cast Deck Panel Field Installation

Figure # 56 Plug patch after grinding

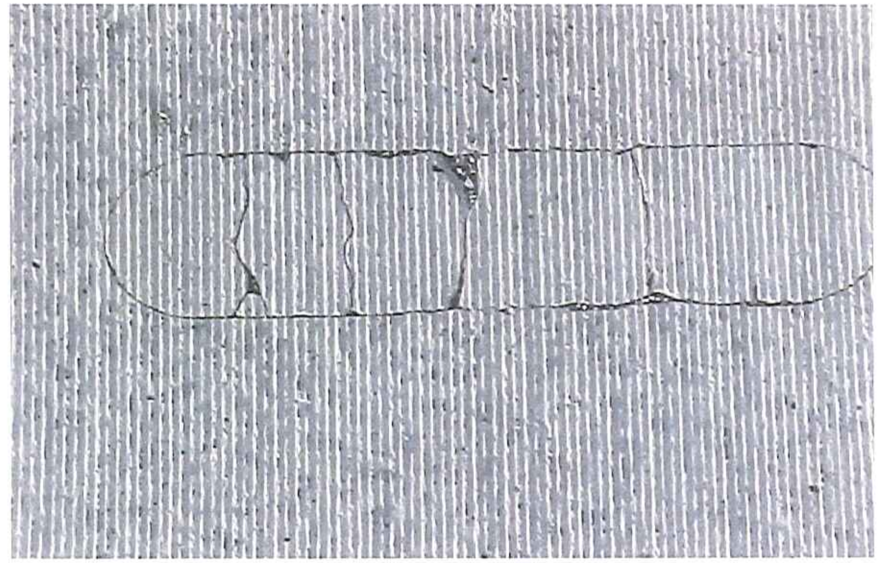

Figure # 57 Non-shrink grout after grinding

Figure # 58 Polymer coating

Figure # 59 Polymer coating

Photo Log - Sub-Structure for Prefabricated Bridge

Figure # 60 Existing Structure

Figure # 61 Spread Footing

Figure # 62 Steel for new structure support

Figure # 63 New foundation for prefabricated structure

Photo Log - Sub-Structure for Prefabricated Bridge

Figure # 64 Demolition of existing structure & New Support

Figure # 65 Existing structure removed & New sub-structure

Figure # 66Temporary footing for prefabricated structure

Figure # 67 Setup for prefabricated structure

Photo Log - Sub-Structure for Prefabricated Bridge

Figure # 68 Structural steel installed at Prefabrication site

Figure # 69 Forms for post tensioning block-outs

Figure # 70 Post Tensioning duck & Block-out

Figure # 71 Steel & forms in End Diaphragms

Photo Log - Sub-Structure for Prefabricated Bridge

Figure # 72 Detail in deck ready for concrete

Figure # 73 Post tensioning block-our and divider plates

Figure #74 Installing post tensioning bars in temp structure

Figure # 75 Post tensioning bars in deck to support ducts

Photo Log - Sub-Structure for Prefabricated Bridge

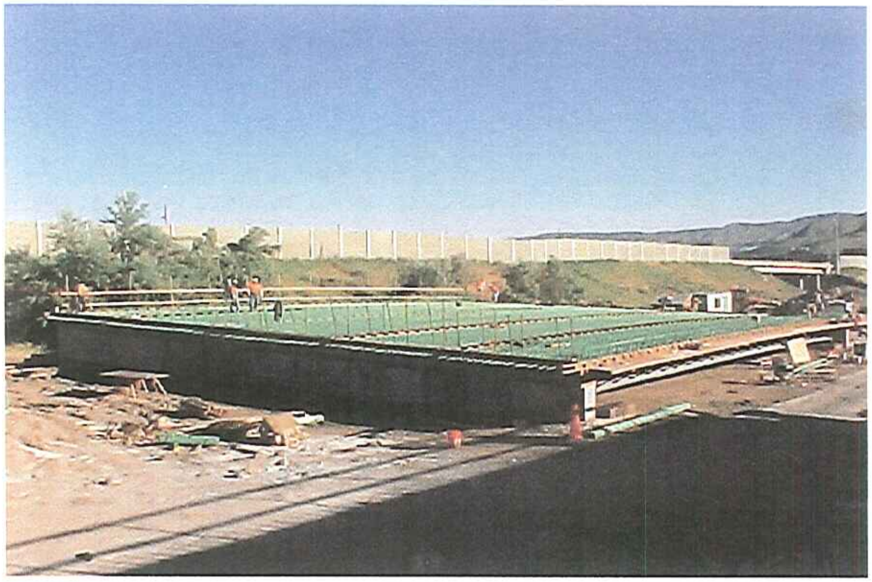

Figure # 76 Prefabricated bridge ready for concrete

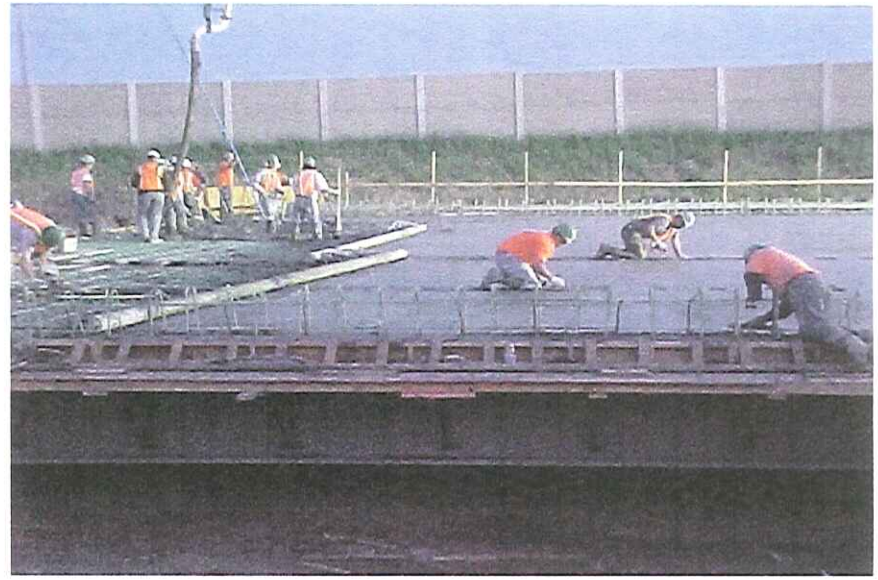

Figure # 77 Placing concrete in prefabricated structure

Figure # 78 Rotation in end diaphragm on temp footing

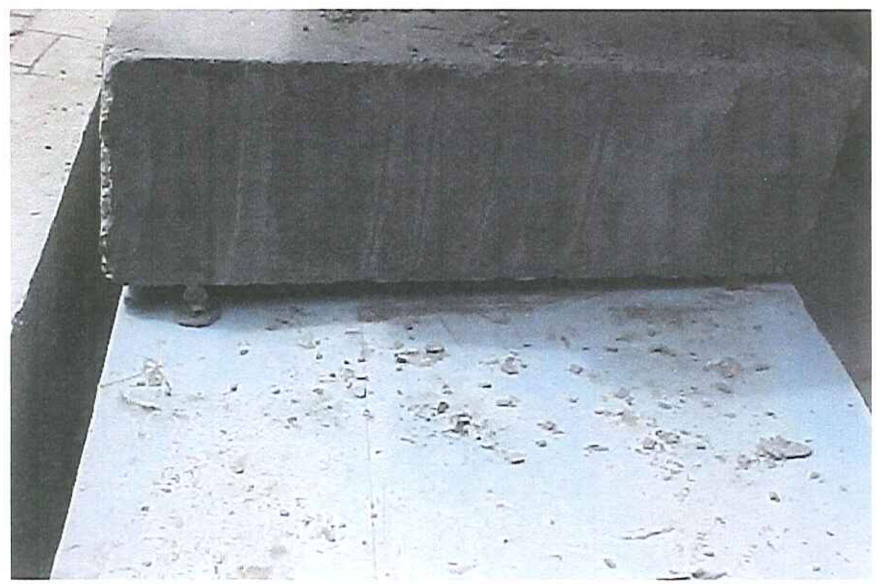

Figure # 79 Seating condition of End diaphragm in final position

Photo Log - Prefabricated Bridge Field Installation

Figure # 80 Lifting bridge element for pre-cast site

Figure # 81 Loading bridge element onto transport unit

Figure # 82 Positioning bride element into final location

Figure # 83 Positioning Bridge element into final position

Photo Log - Prefabricated Bridge Field Installation

Figure # 84 Placing prefabricated bridge elements together

Figure # 85 Placing epoxy on edge of prefabricated element

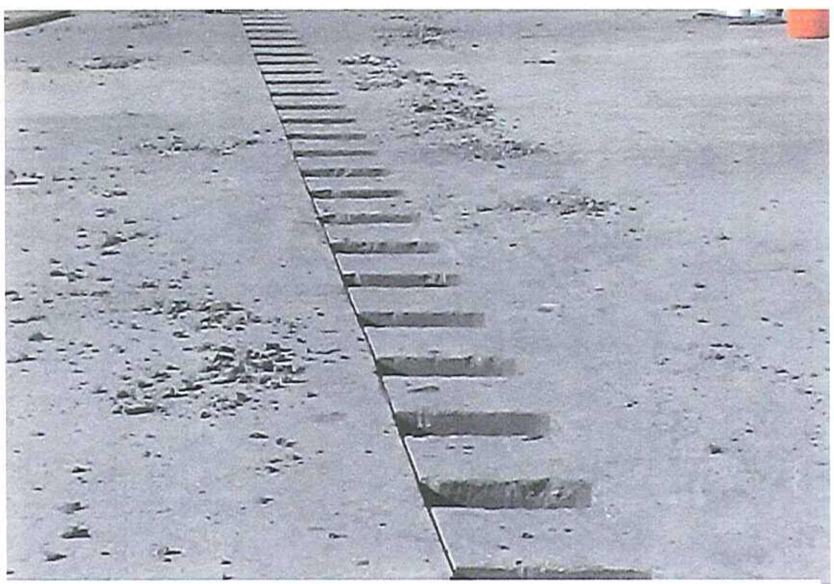

Figure # 86 Longitudinal joint with block-outs for post tensioning

Figure # 87 Vertical alignment of element joints

Photo Log - Prefabricated Bridge Field Installation

Figure # 88 Longitudinal joint with grout plugs

Figure # 89 Vertical alignment of elements

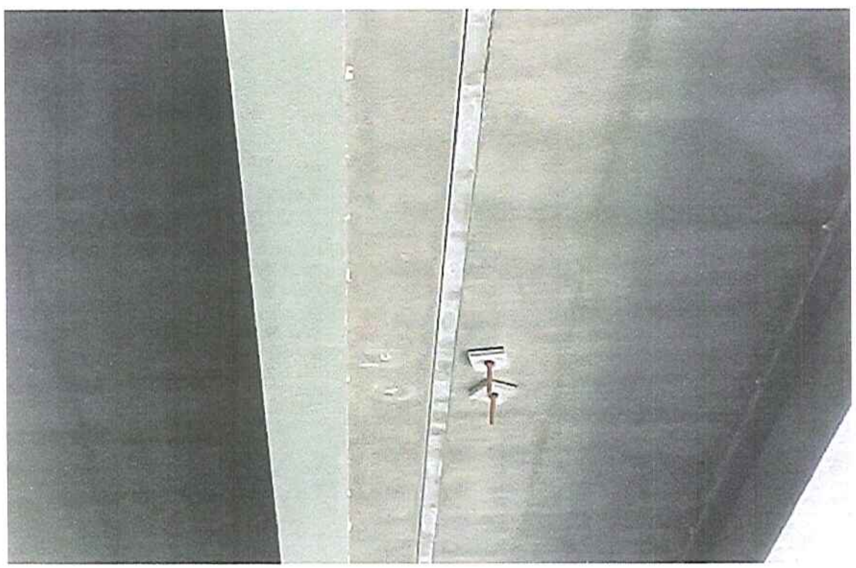

Figure # 90 Longitudinal joint on bottom of deck

Figure # 91 Final position of end diaphragm

Photo Log - Prefabricated Bridge Field Installation

Figure # 92 Installing of post tensioning bars

Figure # 93 Post tensioning bars installed and ready for tensioning

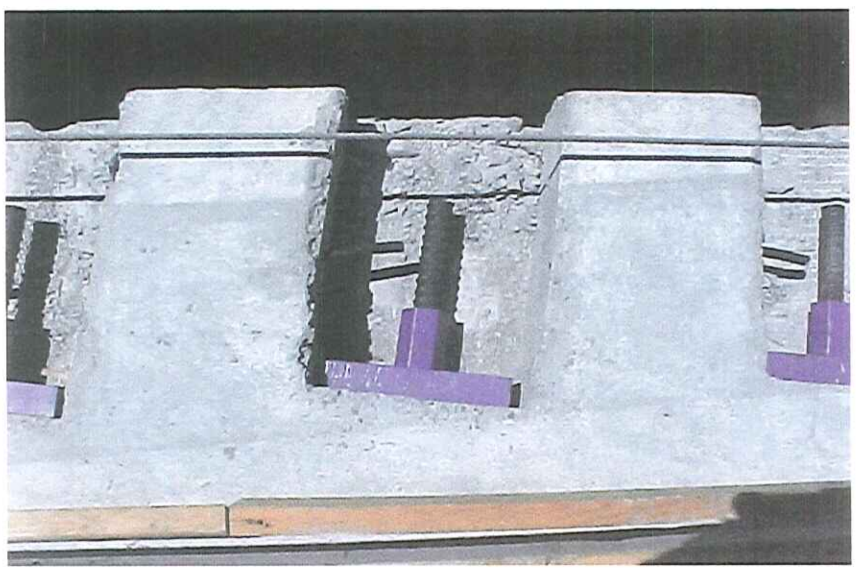

Figure # 94 Initial post tensioning at center of Bridge phase 1

Figure #95 Center of bridge post tensioning connection phase 2

Photo Log - Prefabricated Bridge Field Installation


Figure # 96 Longitudinal joint between phase 1 and 2


Figure # 97 Post tensioning of bars


Figure # 98 Sealing between bar and grout tube

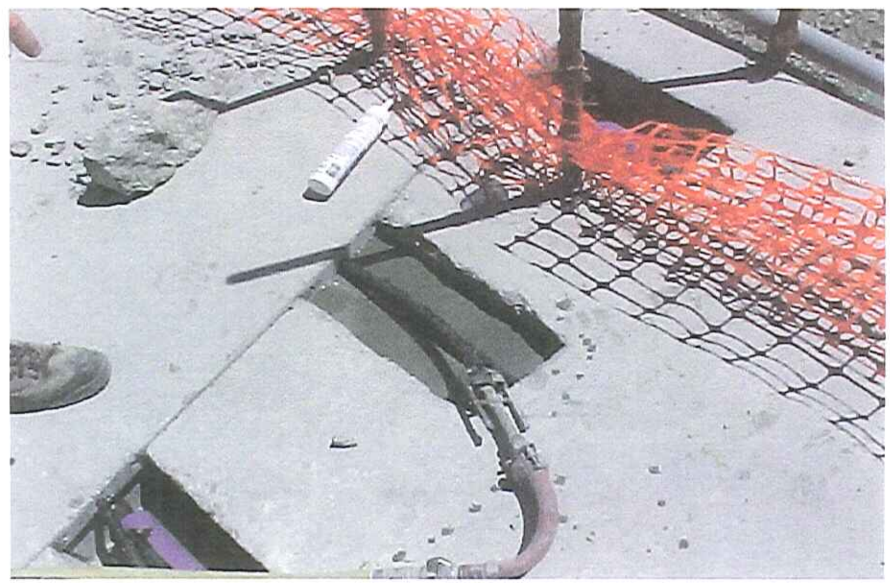
Figure # 99 Grouting between bar and grout tube

Photo Log - Prefabricated Bridge Field Installation

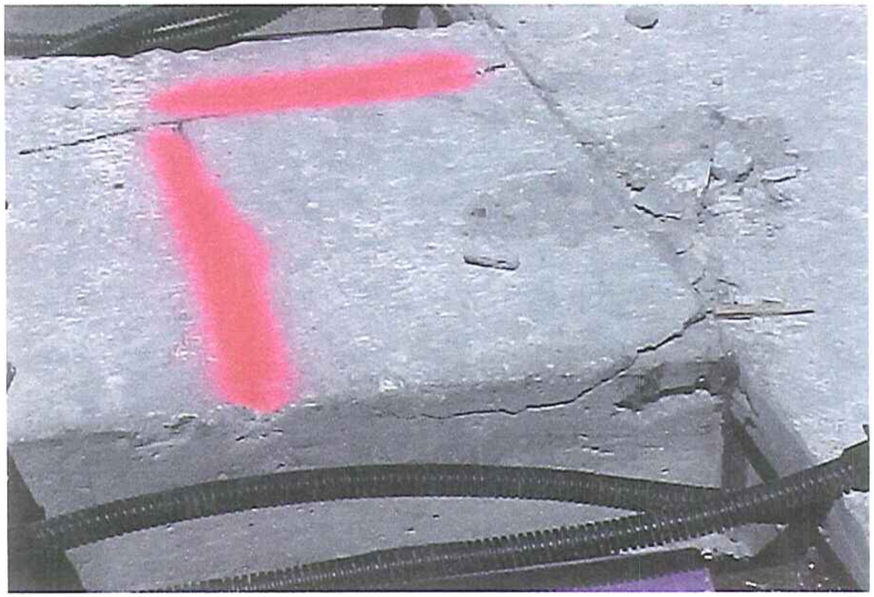

Figure # 100 Failure due to post tensioning

Figure # 101 Repairs between a few block-outs

Figure # 102 Grouting of block-out and grout tubes

Figure # 103 Completing other activities of work

Photo Log - Prefabricated Bridge Field Installation

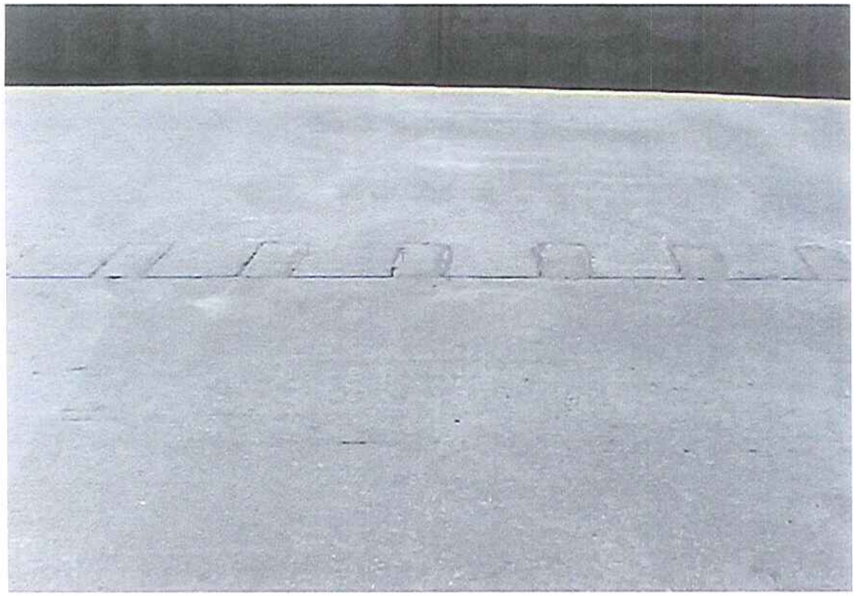

Figure # 104 Post tensioning block-out filled with non-shrink grout

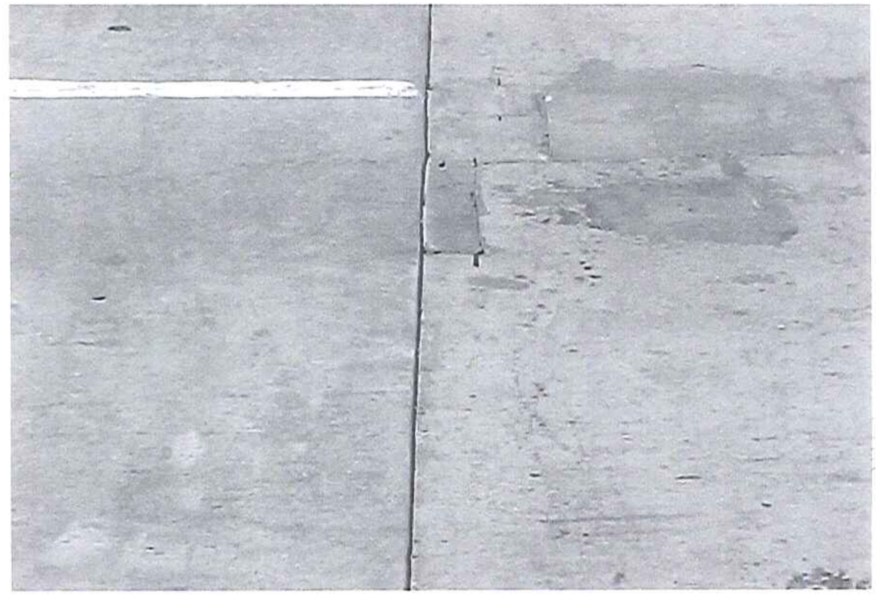

Figure # 105 Prefabricated deck repairs

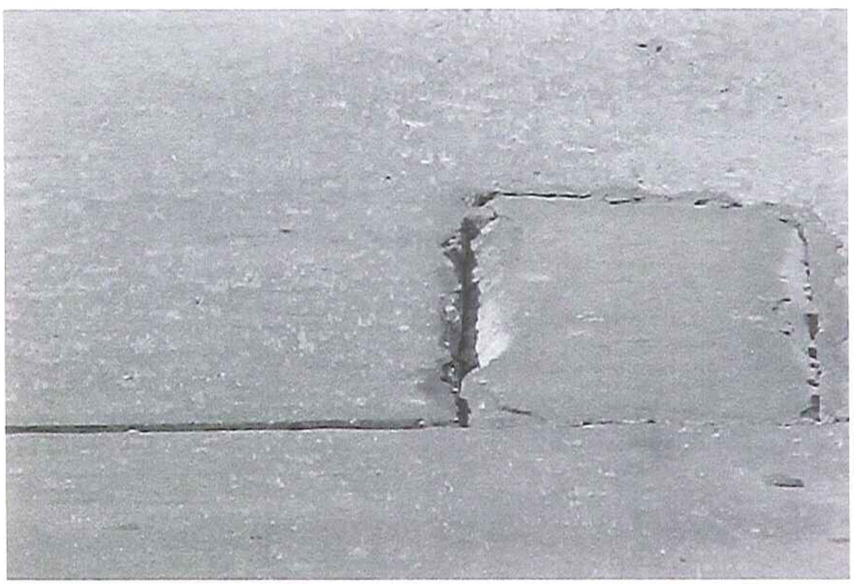

Figure # 106 Close-up of block-out filled with non-shrink grout

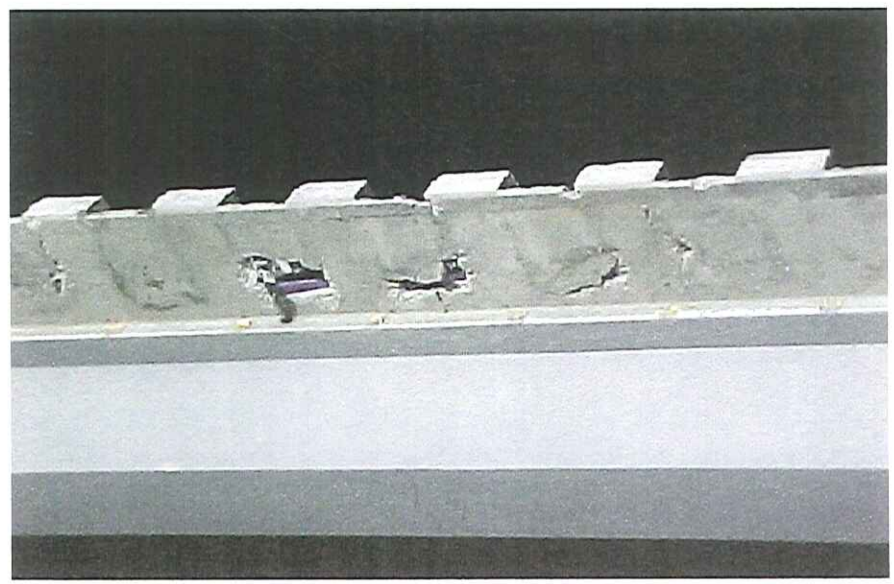

Figure # 107 Weak areas below posts tensioning block-outs

Photo Log - Prefabricated Bridge Field Installation

Figure # 108 Grouting of posts tensioning block-outs

Figure # 109 Cracking across repaired area

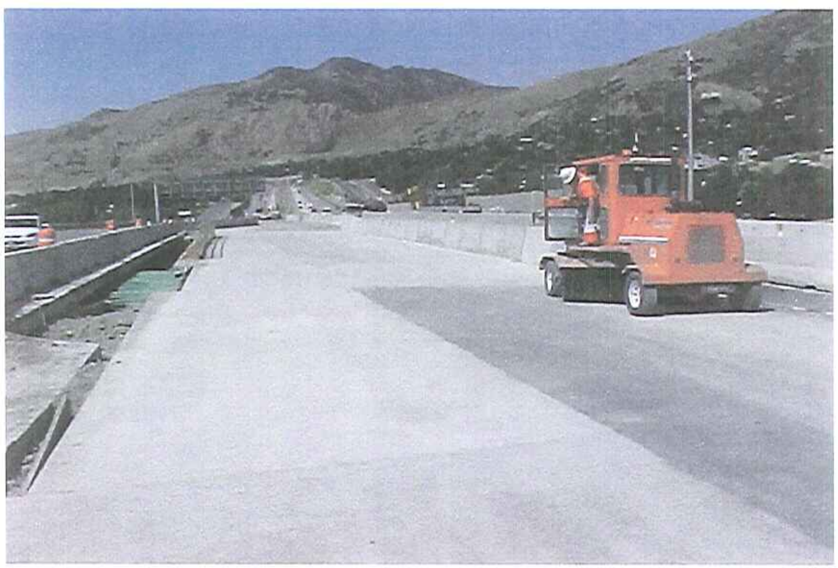

Figure # 110 Bridge ready for opening phase 1

Figure # 111 Bridge under street view

Photo Log – Work Required During Each Phase Before Shifting Traffic

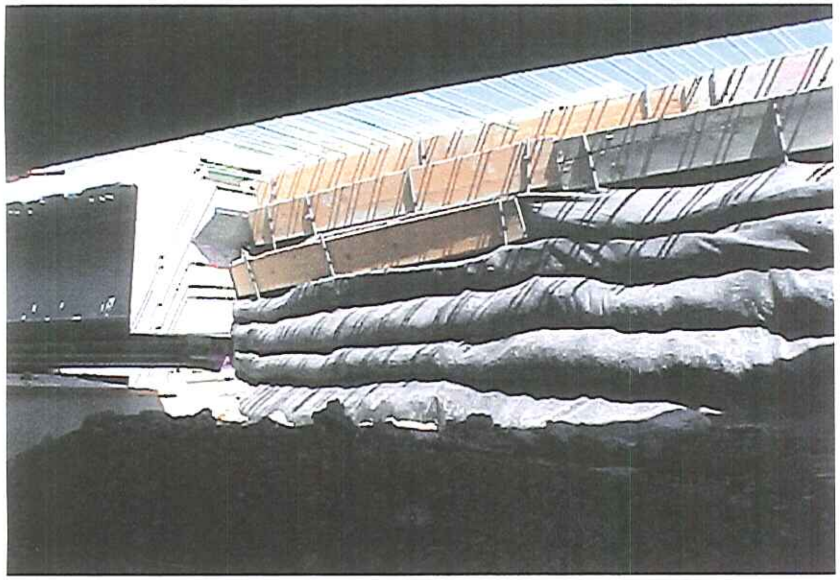

Figure # 112 Elements of work required to open to traffic

Figure # 113 Elements of work required to open to traffic each phase

Figure # 114 Elements of work required to open to traffic each phase

Figure # 115 Element of work required to open to traffic each phase

Exhibit "A"

EVALUATING DESIGN-BUILD vs. TRADITIONAL CONTRACTING METHODS FOR STIP PROJECTS

An Assessment of Travel Impact & Delay Cost

<u>Draft Final Report</u>

UTL – 0604 – 76

Principal Investigator:
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Date of Research: July 2003 – June 2004

June 11, 2004

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ABSTRACT

Highway construction impacts travel time and causes vehicular delays for road users. Innovative construction techniques like the "design build" method can reduce the time of construction activity when compared to "traditional build" methods, thus resulting in reduced network delay. The faster the construction activity occurs, the lower the impact on users and the higher the savings in delay cost. This study is an assessment of the travel and the cost impact due to traditional build and design build techniques of Utah Department of Transportation's five-year road improvement programs; a part of the Statewide Transportation Improvement plan.

The build scenarios were modeled from 2004 until 2008 using a macroscopic "Transportation Planning" simulation model called VISUM. A partial network algorithm was developed to run traffic assignments on reduced networks that represented the project areas. Five Statewide Transportation Improvement projects were identified that were grouped into three analysis areas to analyze the impact comprehensively. The simulation results were quantified in terms of measures of effectiveness viz. vehicle miles of travel, vehicle hours of delay and VHD/VMT (Second Delay). Finally, the delay was converted to daily delay cost to assess the cost savings and suggest the best contracting technique for the projects.

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LIST OF ACRONYMS

UTL	Utah Traffic Laboratory
UDOT	Utah Department of Transportation
WFRC	Wasatch Front Regional Council of Governments
TIP	Transportation Improvement Program
STIP	Statewide Transportation Improvement Program
UTA	Utah Transit Authority

EXECUTIVE SUMMARY

Highway improvement projects have a significant impact on the road user in terms of increase in travel time due to the construction activity. Therefore, construction period plays a significant role in the impact on road users. With the Traditional Build (TB) method, construction time is longer, while innovative Design Build methods can reduce the time of construction drastically. This study is an assessment of TB and design build construction methods to measure the travel impact for five Statewide Transportation Improvement Program (STIP) projects. These are part of the Utah Department of Transportation's (UDOT) five-year road improvement program that incorporates many highway projects funded through federal, state and local agencies.

The macroscopic "Transportation Planning" model, VISUM, was used to simulate various time of day scenarios from 2004 through 2010. No-build (NB), TB and Design Build, also called fast track (FT), scenarios were modeled in the network and traffic was assigned using travel demand matrices for all the years. A partial network algorithm was developed to run traffic assignments on the reduced networks that represented the five projects eventually grouped into three analysis regions. The simulation results were quantified in terms of measures of effectiveness (MOEs) viz. vehicle miles of travel (VMT), vehicle hours of delay (VHD) & Second Delay (VHD in sec/VMT). Then the delay was converted into "delay cost" to measure the impact on the individual projects due to NB, TB and FT.

The findings of the study indicate that the VMT shows an increasing trend for all the projects for NB, TB and FT scenarios without a significant change. For the 700 East project, the daily increase in VMT is 10.4%; for the 7800 South project it is 11.5%, and for the I-215 project the increase in daily VMT is 11.4%. However, there is a significant variation in VHD for all the projects for the NB, TB and FT scenarios.

The 700 East project shows that the daily VHD is much lower for FT than for the TB and NB scenarios. The increase in daily VHD is only 5.6% from 2004 to 2008, whereas, for the TB scenario it is approximately 14.2%. For the 7800 South project it was observed that the PM peak VHD is not much different than the AM peak, suggesting that this roadway needs a capacity augmentation. The PM peak VHD is higher than the AM peak suggesting that construction should not be done during the PM period.

The I-215 project shows that the AM peak VHD for all the scenarios is almost equal, with a marginal difference in the absolute VHD value between the TB and FT scenarios. The AM and PM peak VHD are within the same range for both time periods; the AM is within 320-440 and the PM is within 350-500. This is due to the fact that, since I-215 is an interstate, the travel demand is equal during day and night. In terms of absolute value, the VHD for this project is 1/10 of the VHD for the other two projects. The average second delay for I-215 is the lowest among all the projects for all scenarios. With the FT method, a lower second delay is observed for all the projects. For the 700 E project the savings in second delay with FT compared to TB is 0.91; for 7800 S it is 0.7 and for I-215 it is 0.35. The FT method results in a significant saving in delay cost for all the projects. For the 700 E project the delay cost savings from FT compared to TB is $13 million; for the 7800 S project it is $5.4 million and for I-215 it is $2 million.

From this study it can be seen that the FT method saves significantly in delay cost compared to the TB method. The delay savings observed at 700 E is significant and it is highly recommended that this project be done using the FT method. Also, it is recommended that the construction be done in the off peak periods and definitely not during the PM peak. The highest impact will be due to the 700 East project, followed by the 7800 South and I-215 project.

1. INTRODUCTION

This chapter discusses the background and scope of the project. The first section is a discussion about the Statewide Transportation Improvement Projects (STIP) and the role played by the Governmental agencies with regards to various aspects of these projects. The second section discusses the scope, broad goals, and objectives of the study. The last section explains the organization and general structure of this report.

1.1 About the STIP Projects

The Statewide Transportation Improvement Program (STIP) is a compilation of a number of the Utah Department of Transportation's (UDOT's) five-year highway and transit projects. These projects are a compilation of many highway and transit projects that are financially supported by local, state and federal government [1].

These programs are developed by the State departments of transportation, Metropolitan Planning Organization (MPO), Federal and Local Governments. For the Salt Lake Valley, they are developed by UDOT, local governments, and the Wasatch Front Regional Council of Government (WFRC), which is the MPO of the region. The WFRC is also responsible for developing Transportation Improvement Programs that form a part of the STIP projects developed by UDOT [2].

The horizon year of the current STIP is 2008. All the projects that have been identified within the document receive funding until the horizon year. For every project that is identified, the funding source depends on the type of project and the region where the project is located. The funding sources are federal that constitutes the Federal Transit Funds and Congestion Mitigation and Air Quality Program (CMAQ), or it could be funded by state, local, or county agencies.

This study is an assessment of some of the STIP projects in the Salt Lake Valley Region. The projects that are selected form a part of the WFRC's Transportation Improvement Program (TIP) as well.

1.2 Scope of the Study

This study is an analysis of the STIP projects for design build and traditional contracting methods, to identify if there would be benefits in terms of delay savings for these two methods of contacting. The scope of this study is limited to analyzing five selected STIP projects and to model various build scenarios using simulation tools. Considering the defined nature of the projects, the modeling is done from the year 2004 until 2008, the horizon year of the STIP project. The specific objectives underlining this task are:

- Define the project areas for all five identified STIP projects
- Model various build scenarios using a simulation model
- Define the measures of effectiveness (MOEs) to analyze the simulation results
- Simulate the scenarios for multiple periods of the day to understand travel behavior
- Estimate the travel and cost impacts of the projects
- Recommend the best contracting technique for each project

1.3 Organization of the Report

The report is divided into nine chapters, with subsections in each chapter. The first chapter is an introduction to the project and a broad overview of the STIP projects. The second chapter is the literature review and discusses briefly various studies that have been done with regards to the use of simulation tools for travel forecasting. This section also reviews published articles to demonstrate the travel impacts of construction activities for similar projects in other states. The third section of the report is the methodology that explains in detail the process adopted to meet the research goals and objectives.

The fourth section of the report deals with explaining the projection selections, the factors that were taken into consideration while selecting the specific five projects, and the general project characteristics. The fifth section of the report is a detailed description of the modeling procedure. This includes the explanation of the technique and the tool used, the analysis procedure that was adopted, the long term and short term impacts of the projects that affected the model network, and an algorithm that was developed specifically for the use of the simulation tool.

The sixth section of the report is a description of the various MOEs that were selected and why they were selected. The seventh chapter of the report is a discussion of the results for all the project modeling. The final section of the report includes conclusions and recommendations for the study for all five project areas.

2. LITERATURE REVIEW

Travel demand modeling is one of the most effective ways to understand the long term impacts of transportation projects. However, one of the challenges is to model the travel impact in terms of cost parameters. There are many studies that demonstrate the use of travel demand modeling theory in many ways using simulation models, but very few of these studies address the issue of cost conversion of the travel impact. This chapter will discuss some of the studies that highlight the use to travel demand modeling tools to achieve a certain set of objectives.

DeJohn et al [3] used the travel demand modeling tool Tranplan to assess the statewide impact of long range transportation projects. Various supply and demand strategies that formed a part of the various transportation projects were incorporated into the model. The projections were done for the years 2000, 2010 and 2025. The projections were done for travel demand management, transit rich, ITS/TSM and system capacity augmentation scenarios. The vehicle hours of delay and vehicle miles of travel were used as MOEs to assess system performance under these conditions. This literature highlighted the used of demand modeling tools for assessing various types of policy implications on a system. Hwang et al [4] research deals with estimation of delay and congestion in terms of MOEs like vehicle miles of travel. Although no kind of cost issue is addressed in the study, it deals with parameters that are commonly used as measures in travel demand forecasting studies.

The research work performed by Leurent Fabien [5] is one of the very few works that discusses the issue of cost vs. time in traffic assignment models. The author ascertains that most of the travel demand models convert the delay into a cost factor to bring the cost-benefit factor into account. So the author in the paper identifies the cost vs. time as an economic phenomenon and then develops mathematical models to demonstrate the effect of travel time on cost.

Ross et al [8] did a study and documented a NCHRP synthesis on the treatments for work zones. The author recommends using a straight dollar value and multiplying it with the delay to get the travel time benefits for a project. This methodology was adopted in this study keeping in mind the scope of this project.

Forkenbrock and Weisbrod [11] published some guidelines in the form of an NCHRP report that deal with assessing the social and economic impacts of a transportation project. This guidebook addresses vehicle operating costs, but does not suggest any method for user delay cost calculation. However, this book is useful in understanding the likely travel impact of transportation projects and the easiest way to assess them. The research is very comprehensive in explaining the different aspects of travel demand modeling and its travel impact on commuters.

The above mentioned studies are some of the examples that deal with the dynamics of travel demand forecasting, but there are far fewer studies that deal with the conversion of delay to cost.

3. METHODOLOGY

The methodology of this study was primarily divided into three stages: identifying the relevant projects; modeling various scenarios, and the final analysis. Figure 3.1 is a diagrammatic representation of various stages of the research process. The following sections will discuss each stage in detail.

In the first stage of the study, a few of the relevant projects are selected from UDOT's Statewide Improvement Program (STIP) plan of 2004-2008, keeping in mind the overall scope of the project. The selection of the projects was based on the limitations of the model network, the recommendations made by UDOT and the project type. The project type decision is based on the overall estimated project cost as listed in the WFRC's Transportation Improvement Plan (TIP) plan of 2004-08, and the impact area of the project in its vicinity.

The second stage of this study was to model various scenarios individually for the selected projects. The simulations were done using the macroscopic "transportation planning" model VISUM that was calibrated for the Salt Lake Valley region by a research team at the Utah Traffic Lab for an earlier study. Since the network of the STIP projects is smaller than the available network in the model, a partial assignment algorithm was used to simulate the scenarios for the smaller regions. The results of the simulations are quantified in terms of certain MOEs for the no-build; traditional build and design build (fast track) scenarios. The AM, PM, MD and EV, and OD matrices are assigned on all three scenarios to quantify the impact for different times of day.

The VISUM simulation model works on the four step travel demand modeling procedure. Three of the four steps are already done by WFRC and so the matrices used in this model are taken from WFRC's transportation planning models. The assignments using VISUM works on an algorithm, as mentioned above, that was developed specifically to analyze the smaller networks like the ones in these projects. This algorithm is generic and can be applied for any other network transformation procedure in VISUM. The algorithm and the procedures are discussed in the subsequent sections of this report in detail.

The last stage of this study was to convert the MOEs in terms of delay cost to understand the implications of the projects. The simulation results are quantified both in terms of travel impact and delay cost. At the end the project, savings in delay cost are identified and the best contracting method is recommended for all project types.

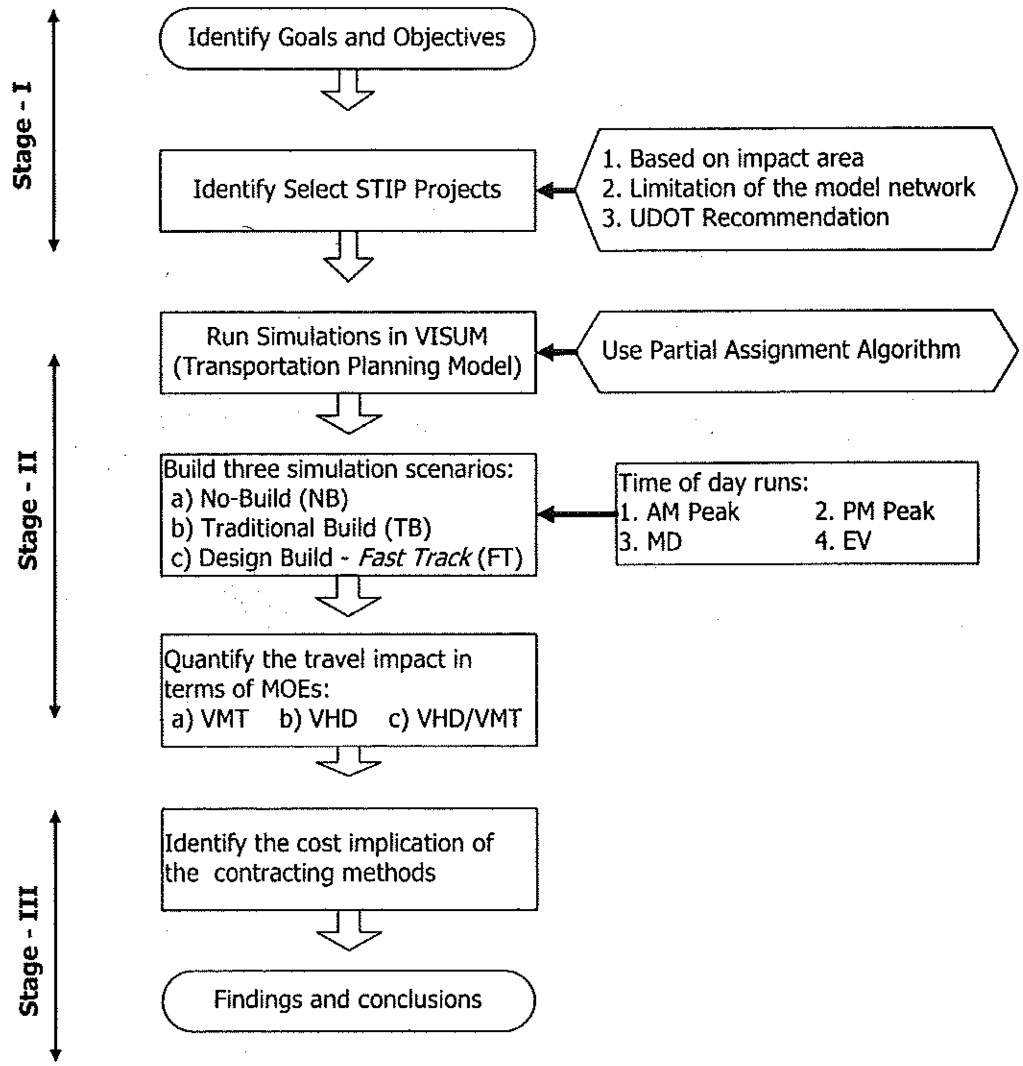


Figure 3.1 Research Methodology

4. PROJECT SELECTIONS

This chapter describes the projects that were selected for modeling and the network characteristics for each one. Considering the scope of the study, a total number of five were considered for analysis. As mentioned earlier, the selection was based on the total STIP estimated cost, UDOT recommendations and the limitations of the model network. Another factor that was taken into consideration was the impact area. Vicinity to major arterials was considered as a potential impact on the network and so the project was selected. The subsequent section will discuss each project in detail and its area characteristics.

4.1 Project # 1 – State Street & 10600 South

This project is located at the intersection of two major arterial roads: State Street and the 106th South. State Street is a major arterial and any construction activity on the section will likely have an impact on the street and its surrounding area: 106th South is a major arterial that feeds into I-15 South. The proposed construction activities documented in WFRC's Transportation Improvement Program 2004-2008 [1] plan are:

- Widening of the State St. at the intersection on the east by 14'
- Accommodation of an additional left turn lane on 10600 South from State St.
- A small portion of widening on the west side of State St.

Figure 4.1 shows the project area and its vicinity. Table 4.1 is the summary of overall project characteristics as documented in the TIP plan.

Table 4.1 Project Characteristics (State St. & 106th S)

Type of work:	Intersection improvement
Estimated project cost:	$ 3,224,270
Potential impact area:	State St., 106th S and 700 E

Source: Transportation Improvement Program 2004-2008, WFRC

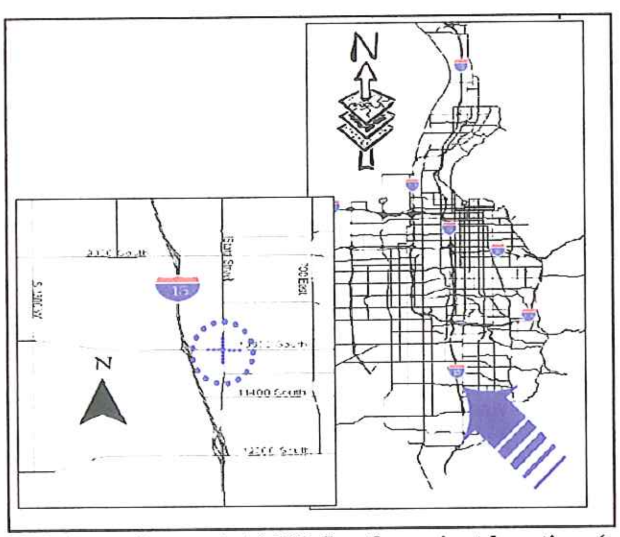


Figure 4.1 State Street & 10600 South project location *(source: TIP)*

4.2 Project # 2 – 7800S (between Redwood & Bangerter)

This project is on one of the significant east-west corridors in the Salt Lake Valley and is between two of the most heavily used arterial roads, Redwood Rd. and Bangerter Hwy. The construction activity on 7800 S between these two arterials will have an impact not only on 7800 S, but also on these two arterials. This is likely to impact the travel pattern in the vicinity of these two roads as well. The proposed construction activities documented in WFRC's Transportation Improvement Program 2004-2008, [1] plan are:

- Widening from 2 to 4-5 lanes on 7800 S from 2700 W to 1850 W
- Widening and re-construction from 2-4 lanes to 4-5 lanes on the 2700 W until Bangerter HWY

The proposed construction activity is aimed to relieve traffic congestion on this heavily traveled route and to augment the capacity of the existing roadway. Figure 4.2 depicts the construction area and its impact area in the vicinity. Table 4.2 is the overall characteristics that account for construction activity on both sections of the roadway.

Table 4.2 Project Characteristics (7800S)

Type of work:	Lane widening
Estimated project cost:	$ 21,750,820
Potential impact area:	Redwood Rd., Bangerter HWY, 7800 S

Source: Transportation Improvement Program 2004-2008, WFRC

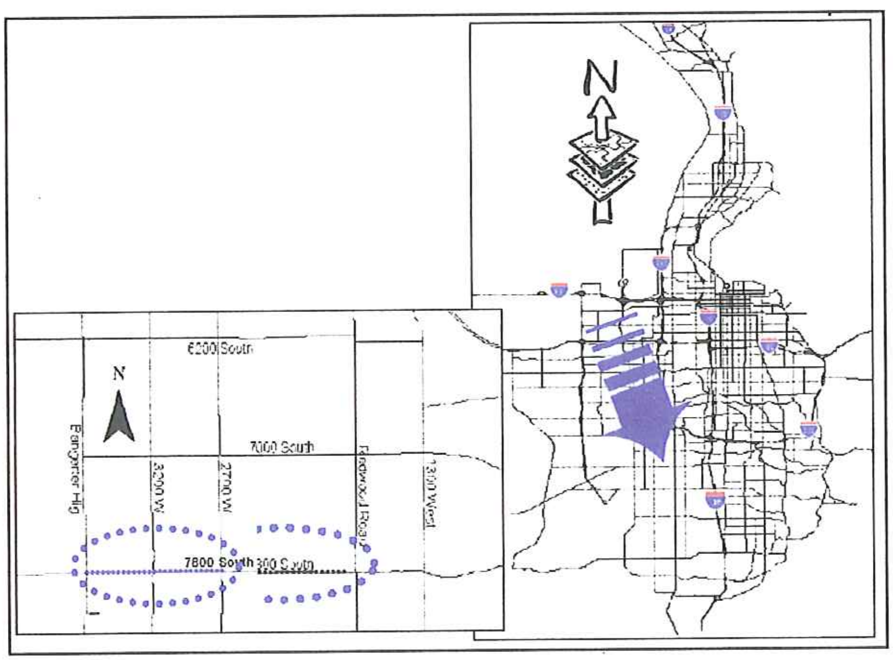


Figure 4.2 7800 S - 2700W to 1850W & 2700W to Bangerter HWY ***(source: TIP)***

4.3 Project # 3 – 700 E (9400 South to 10600 South)

700 E is one of the most heavily traveled roadways in the Salt Lake Valley region and any construction activity will have an impact on the road and its travel pattern. The presence of State St. to the west, 106th S to the south and 9000 S to the north defines the impact area for this project. 700 E is classified as a "principal arterial" by UDOT's functional classification system. The project was identified in 1999 in WFRC's Transportation Improvement Program plan. Some of the proposed construction activities enumerated by the TIP 2004-2008 document [1] are:

- Widening to two lanes in each direction on the 700 E
- Shoulder improvements and improvements of the signalized junctions along the travel way

The proposed construction activity is aimed to relieve traffic congestion on this heavily traveled route and to augment the capacity of the existing roadway. Figure 4.3 depicts the construction area and its impact area in the vicinity. Table 4.3 contains the overall characteristics.

Table 4.3 Project Characteristics (700E)

Type of work:	Widening from 2 to 4-5 lanes & shoulders
Estimated project cost:	$ 19,873,000
Potential impact area:	700E, State St., 10600 South & 9000 South

Source: Transportation Improvement Program 2004-2008, WFRC

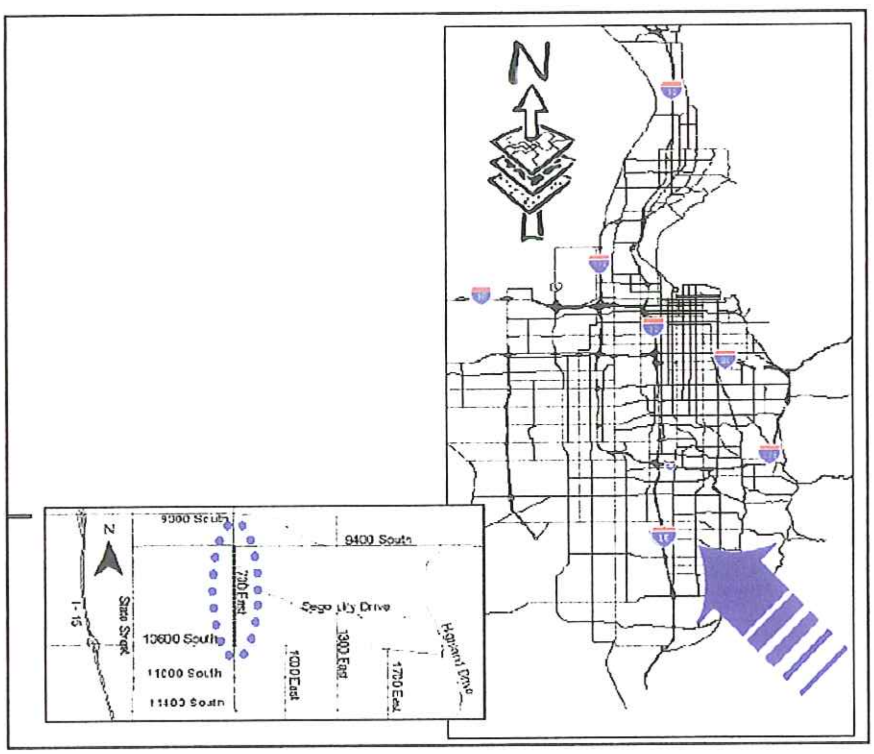


Figure 4.3 700E – 9400 South to 10600 South *(source: TIP)*

4.4 Project # 4 – State Street TRAX Crossing

This project is one of the bridge replacement projects for the Utah Transit Authority's (UTA) TRAX system. In addition, an intersection improvement is also proposed between 7800 South and 8600 South in this project area. Some amount of traffic impact is anticipated, although the bridge replacement will not cause a direct impact on network performance since the bridge is a rail bridge and not a roadway facility. The intersection improvement will definitely render some impact on State Street and, since this is a significant travel mode, some traffic impact is anticipated. The proposed construction activities enumerated by the WFRC's Transportation Improvement Program 2004-2008 document [2] are:

- Intersection improvement between 7800 south and 8600 south
- TRAX bridge replacement

The bridge replacement will be a double tracking on the State Street Bridge to increase frequency and alleviate safety concerns. Figure 4.4 depicts the construction area and its impact area in the vicinity. Table 4.4 contains the overall characteristics.

Table 4.4 Project Characteristics (State Street TRAX Bridge & X-ing)

Type of work:	TRAX bridge replacement & intersection improvement
Estimated project cost:	$ 10,000,000
Potential impact area:	State Street roadway

Source: Transportation Improvement Program 2004-2008, WFRC

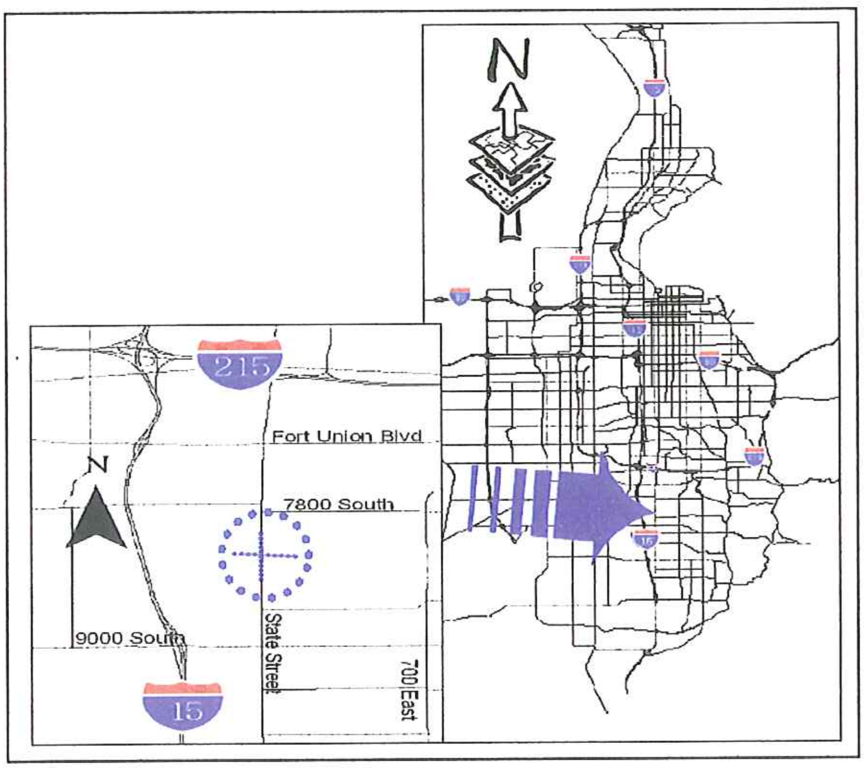


Figure 4.4 State Street TRAX Bridge & Intersection ***(source: TIP)***

4.5 Project # 5 – I-215 Bridge-replacement (on I-215 at 3900 South)

This project is one of the bridge replacement projects on I-215 and is one of the first projects done by UDOT that uses pre-fabricated construction technology. This technology, although it is more expensive than the traditional construction techniques, saves a significant amount of construction time, thus saving delay cost associated with commuter delay. Since I-215 is a major roadway, it will be impacted by the construction activity. However, using a pre-fabrication technique may lead to savings in user delays; therefore, the assessment of this project was considered necessary.

Since the activity involves bridge replacement and direct construction activity on the interstate, there will be a capacity reduction on the facility that may or may not impact the travel pattern of the region. Some of the project details are enumerated in Table 4.5.

Table 4.5 Project Characteristics (I-215 Pre-fab Bride Replacement on I-215 at 3900 South)

Type of work:	Bridge replacement
Estimated project cost:	$ 4,350,000 (Pre-fab cost estimation)
Potential impact area:	I-215 interstate

Source: Transportation Improvement Program 2004-2008, WFRC

5. MODELING PROCEDURE

This chapter will discuss the modeling procedure for simulating the selected projects for all the scenarios and all the years under consideration. The chapter is divided into three sections. The first section is a discussion of the overall modeling approach. It includes a discussion of the simulation scenarios considered and the rationale for grouping the projects into three project areas. The second section is a discussion of the simulation tool VISUM and the last section explains the algorithm that was developed to run the simulations in VISUM for small networks.

5.1 Defining Analysis Areas

The overall modeling approach was based on defining an analysis area to capture the impact, not only on the effected section, but within a region. Using this approach, three analysis areas representing all five projects were defined. Three of the five projects were grouped into one area and the other two projects were kept as separate analysis areas.

Projects 1, 3, and 4 (State St. & 10th S; 700E and State St. TRAX crossing) were grouped into one analysis area. The project on 7800 S was kept as a single analysis area and the project on I-215 was again defined as a separate analysis area. The following criteria were taken into consideration while defining the analysis areas:

- Proximity of the project area to major arterial roads within the immediate region
- Presence of a group of projects in the same region
- The project type and the severity of the construction project on the road user

Analysis area 1, comprised of projects 1, 3, and 4, had two projects on State St. (project #s 1 & 4) and one project on 700 E (project #3) that was near the State St. projects. Projects 1 & 4 were less severe than the project on 700 E, so they were grouped together.

Analysis area 2 is comprised of only the 7800 S project (project #2) because this project was within two major traveled arterials: Redwood Rd. and Bangerter Hwy. The construction activity on 7800 S would likely have an impact on these two arterials as well, so this was defined as a separate area.

Analysis area 3 is comprised of the I-215 project only. It was considered important to model the network that was likely to be impacted by construction activity on the interstate, so this was kept as a separate analysis area.

5.1.1 Considering Long Term & Short Term Impact on Project Area

After defining the analysis areas, the short and long term impacts of the projects were defined prior to assigning traffic using the simulation model. This was important because some of the projects that had lane widening will have a permanent impact on the network since the lane capacity will change. Whereas, some of the other projects that involve intersection improvement or a bridge replacement will affect the network capacity only temporarily and will not cause a permanent network change. Table 5.1 explains the impact for all the projects.

Table 5.1 Long & Short Term Impacts of the projects

Project	Type	Impact
#(1) State St., 106th South	Intersection improvement	Long term – network change
#(2) 7800 S	Lane widening	Long term – network change
#(3) 700 E	Lane widening	Long term – network change
#(4) Sate St., TRAX Bridge	TRAX Bridge	Short term – no change in network
#(5) I-215	Bridge replacement	Short term – no change in network

Defining these changes will lead to changes in the model network and the simulations will be different for each individual project depending on these short term and long term changes. For projects 1, 2 & 3 the network in the model needs to be changed and the capacity on the specific links need to be changed after construction ends. This will impact travel since the capacity will increase at a future date. For projects 3 & 4 there is no change in the model network because there is reconstruction. Hence, the network remains the same for all the years.

5.1.2 Simulation Scenarios

Three simulation scenarios were identified to model the impact of all three analysis areas using the simulation tool VISUM. The first scenario was the no-build (NB) scenario. This means there would be no construction or any capacity augmentation and the demand would be met by the existing capacity for all the model years. This does not take into account any of the projects and the future travel projections are based on the assignment of the matrices on the existing network.

The traditional build (TB) scenario means that the construction activities for all five projects defined within the three analysis areas will continue with the traditional build technique. This scenario would continue from 2004 until 2010 for a period of five years. This scenario was modeled taking into account the long term impact of the construction activity. Therfore, the network would function at a reduced capacity throughout the construction period, from 2004-2008. So the simulations are run assuming a TB construction period from 2004-2008 and a FT construction period from 2004-2005.

The third scenario was the design build or the fast-track (FT) scenario. This means that the construction time for all the projects is short and the benefits in terms of capacity augmentation on the project network are achieved sooner. It was assumed that the design build method will take one year from 2004-2005. The traffic assignment for the years 2006-2010 was done on the improved network that resulted from the construction activity.

The difference in traditional build and design build is that, with traditional build, the benefits obtained as a result of the improvement of the road capacities will come into effect after a longer period of time. Whereas, for design build, the benefits will come into play after one year, once the construction activity is over. So the traditional build scenario will get the same benefits as the design build after the year 2010, when construction has ended.

5.2 Incorporating Work Zone Capacity

Notwithstanding the short or long term impacts, the capacity of the roadway is affected during the construction period. Therefore, to model the construction sections, work zone capacity standards were incorporated into the model on the effected links. For the freeway sections on I-125, a work zone capacity of 1600 phpl (source: HCM) was used to model the network. For the other projects, the existing capacity of the roadway was reduced by approximately 13% from the original to model the construction period scenarios. For other urban roads the capacity values, as suggested by the National Cooperative Highway Research Program's (NCHRP) synthesis 208 on "Work Zone Capacity," were used as shown in table 5.2.

Table 5.2 Construction Capacity Values

	Basic Capacity (vph)	Work Zone Capacity (vph)
Multi lane highway		
3 lanes in each direction	5,700	4,220
2 lanes in each direction	3,800	2,880
1 lanes in each direction	--	1,570
Urban Intersection		
3-lane approach	1,900	1,650
2-lane approach	1,350	1,100
1-lane approach	800	500

Source: NCHRP Synthesis 208

These capacity values were incorporated into each network for various scenarios (TB, FT, and NB) for the simulation years 2004 thru 2010. It should be noted that the reduced capacity values were applied only for the construction sections and for the period during which construction activity took place.

5.3 Using VISUM-'Transportation Planning Model'

To simulate the impact of all the projects for all the scenarios VISUM, a macroscopic transportation demand modeling software, was used. This simulation tool is widely used for transportation planning and travel demand modeling. The core of the model is the four step travel demand forecasting procedure. The model is capable of performing travel forecasting analysis and has capabilities that can be manipulated by the user for specific uses.

Calibration of this model was not necessary for this study since it was done earlier for a previous research study at the Utah Traffic Lab. The previously calibrated version was used for various traffic assignments for the project areas. However, an algorithm was developed that was used for traffic assignments for smaller project regions that were used in the model for traffic assignments. This will be discussed in more detail in the subsequent sections. Some of the characteristics of the model are discussed below.

The network characteristics for the whole transportation network in the Salt Lake Valley region are defined in terms of links and nodes in the model. WFRC has divided the region into 600x600 TAZs and the model uses the same divisions. The links and the nodes form a part of the 600 zones within the region. All the nodes in the network are defined by the turning relations that govern the direction of traffic. These relations can be exported into micro-simulation models like VISSIM to perform a more detailed analysis if needed. Like all other travel demand modeling tools, VISUM is also based on time based assignment procedures. The traffic assignments for this study were done using the "equilibrium traffic" assignment procedure.

5.4 Developing Partial Assignment Algorithm

The simulation model available had a network for the whole Salt Lake Valley region. Since the analysis areas have a network that is smaller than that, it was necessary to reduce the network and assign the traffic on the reduced network. A partial assignment algorithm was developed in accordance with the underlining principles of the model and was used for partial network assignment. Figure 5.1 is a conceptual representation of the underlining principle.

The first step of the algorithm is to input the base network (of the whole Salt Lake Region) and assign the base OD matrix. The simulation runs are done for all the times of the day: AM peak, PM peak, MD and EV periods. Once the traffic has been assigned, the analysis area network is activated and the partial network generation operation command is used. This also prompts the model to re-read the OD matrix and reduces the total assigned trips to the ones only in the region. This creates a new OD matrix that has trips that are comprised of intra-zonal and inter-zonal trips only. The trips that do not pass through the smaller network are eliminated because they are external trips that do not pass through the analysis area at all. The new smaller network that is generated is defined with default internal node numbers and the external zones. This operation is done for all the scenarios and for all periods of the day on all three analysis areas.

At this point it is also necessary to check the assigned traffic on the reduced network links with the base assigned network traffic to make sure that the assignment has been run correctly. If any discrepancy is found, the second stage of the algorithm must be repeated. If the assignment is correct, the final version is saved and the required data is exported from the partially assigned network for further analysis. Figure 5.2 shows all the steps of the algorithm and the process.

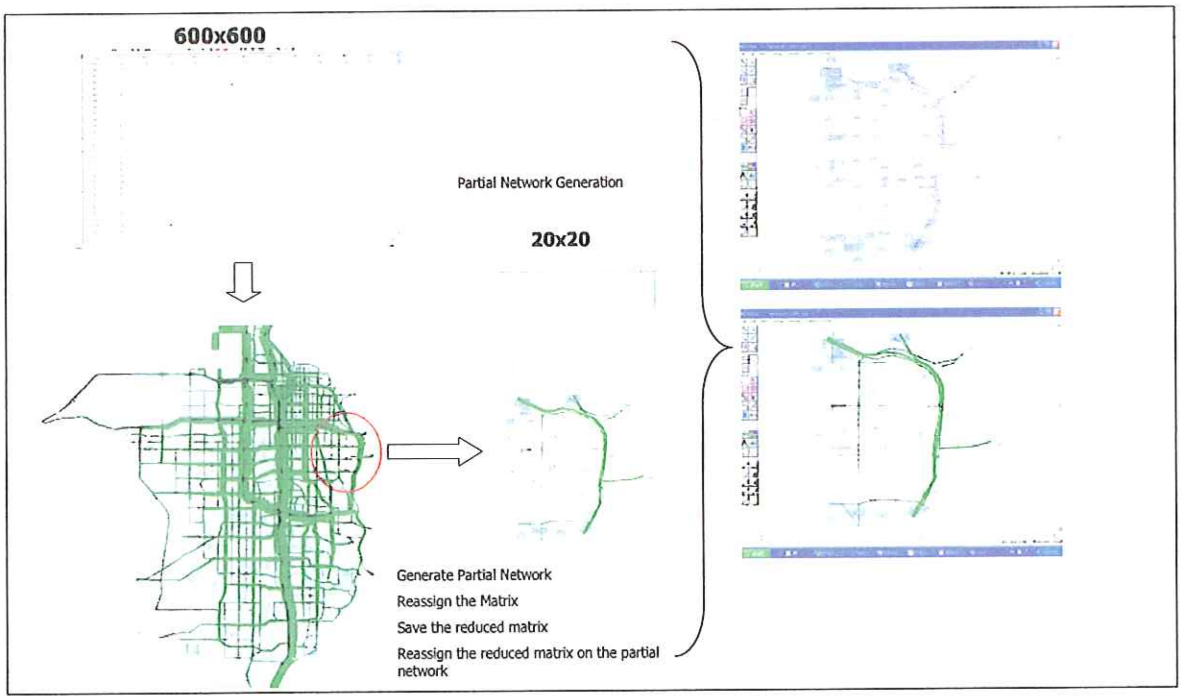


Figure 5.1 Conceptual Representation of the Partial Assignment

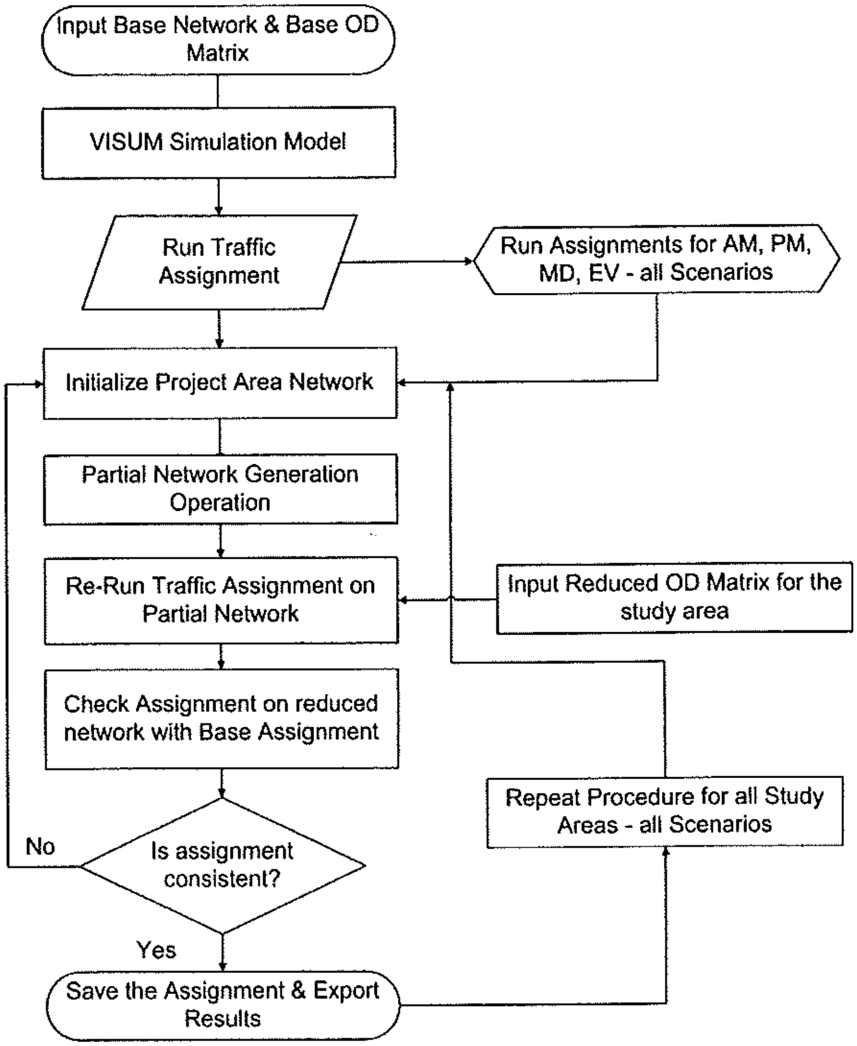


Figure 5.2 Partial Assignment Algorithm

6. MEASURES OF EFFECTIVENESS

This chapter will discuss the MOEs that were identified to analyze the impact of the projects and the methods to compute from the traffic assignments. The MOEs were selected, keeping in mind the underlining objective of analyzing the long term travel impact, the user delays due to the construction activity and the type of simulation model used.

6.1 Vehicle Hours of Travel (VMT)

A vehicle mile of travel is defined as the product of the sum of the total miles of travel on a roadway and the total number of vehicles at a given point in time. It can be expressed as a yearly value or a daily value depending on the travel assignment. For this study the travel demand matrices that are assigned are yearly. VISUM is based on a network definition with links so mathematically the VMT computation can be expressed as:

$$VMT_t = \sum_{i=1}^{n} link_i x vol_t$$

where:
t= simulation time
i= link number (from 1 to n)
vol_t = volume on link 'i' at simulation time 't'

In this study, the VMT values are computed for all times of days, for all the simulation years (from 2004 until 2010), and for all the three analysis areas. VMT is a measure of the total travel miles on a roadway facility that reflects the travel demand for a region. A higher VMT value suggests that the travel demand is higher for the region and suggests a travel pattern that has a higher number of vehicles traveling within the region.

6.2 Vehicle Hours of Delay (VHD)

Delay on a network is the time taken in hours for a vehicle to travel at the congested speed minus the time taken in hours to travel at the ideal speed [3]. The total vehicle hours of delay for a system is the product of this factor with the total number of vehicles traveling within the system at a given simulation time "t." In other words, the total delay is the product of the total vehicle hours traveled within the system multiplied by the total number of vehicles. Mathematically it can be expresses as:

$$VHD_t = \sum_{i=1}^{n} \left[(t_c - t_f)_t \, x vol_t \right]_i$$

where:
t= simulation time
i= link number (from 1 to n)
t_c = current travel time after simulation on link 'i' at simulation time 't'
t_f = free flow travel time on link 'i' at simulation time 't'

In this study, the VHD values are computed for all times of day, for all the simulation years (from 2004 until 2010), and for all the three analysis areas. The current travel time "t"$_c$ is the current time of travel with the congested speed and the time, t_f is the time of travel at a free flow speed. VHD is a very efficient way of measuring the total system delay within a system and can also be expressed as the user delay value.

6.3 Second Delay (VHD in sec/VMT)

This MOE is defined as the ratio of the VHD expressed in seconds with the total VMT for a region. Second delay helps to measure the total delay within the system per vehicle miles of travel. A higher VHD or VMT value within a system does not necessarily suggest that the system is performing sub optimally, hence this MOE helps to resolve this discrepancy. Mathematically it can be expressed as:

$$VHD / VMT = \sum \frac{VHD_t}{VMT_t}$$

where:
VMT_t = vehicle miles of travel at simulation 't'
VHD_t = vehicle hours of delay at simulation 't'

Second delay can be computed to understand the system behavior for the whole system or for individual links within the system. It is an effective way to comprehend the effect on delay within a network. For this study this MOE is used for all the analysis areas and all three scenarios.

7. RESULTS

This chapter is a discussion of the analysis of the simulation results for the different build scenarios. The results are quantified in terms of the MOEs mentioned in the previous chapter and travel impact is assessed. The cost implication, which is expressed in terms of user delay cost, is also a part of this chapter that will be discussed in one of the sections.

7.1 Travel Impact in terms of VMT & VHD

This section will discuss the VMT and the VHD values for all the analysis areas for all five projects for the AM peak, PM peak and daily periods. The results are first explained for the daily values and then are broken down in two sets of graphs representing the AM and PM peak periods separately. The VMT values are discussed first, followed by the VHD values.

7.1.1 Project# 1,3&4 (700E & 10600S)

It can be seen in Figure 7.1 that the daily VMT shows an increasing trend over the years for all the build scenarios. The VMT in 2010 shows an increase of 11.6% from 2004 and the increase is gradual over the years. This would mean that the travel pattern is not drastically affected by the construction activity over the years for all three build scenarios. This means that the trip changes will be minimal for all the scenarios. In terms of absolute number, the VMT increases from approximately 1925000 in 2004 to 21750000 in the year 2010. If we compare the daily graph with the AM and PM peak periods, it suggests that the travel demand during the off peak hours is significantly less than the peak hours.

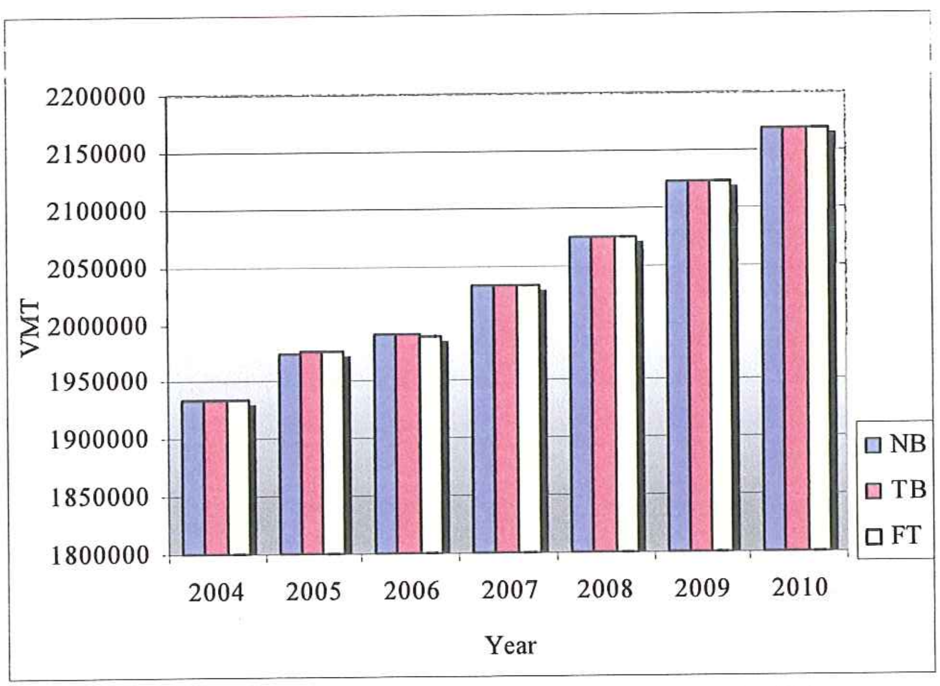


Figure 7.1 Project# 1,3&4-Vehicle miles of Travel (Daily)

Figures 7.2 and 7.3 show that the PM peak VMT is much higher than the AM peak and the PM peak has almost two times the VMT as the AM peak. For both the periods the growth is approximately 10.3% over the years. This tells us that 700 E is a major arterial and is unlikely to have a change in travel pattern over the years. Also, it is concluded that the PM peak period will have a higher impact than the AM peak period. The increase in VMT is gradual through 2005-2006 but is much sharper from the years 2007-2010. In terms of absolute number, during the AM peak period VMT varies from approximately 320000-360000 and the PM peak VMT varies from 520000-590000 over a period of seven years.

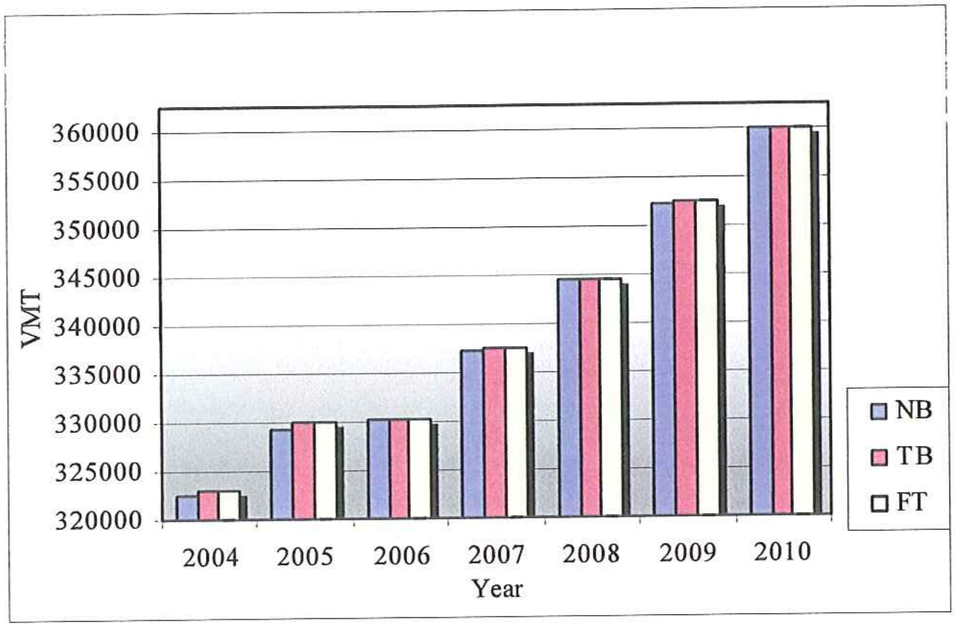


Figure 7.2 Project# 1,3&4-Vehicle Miles of Travel in AM peak Period

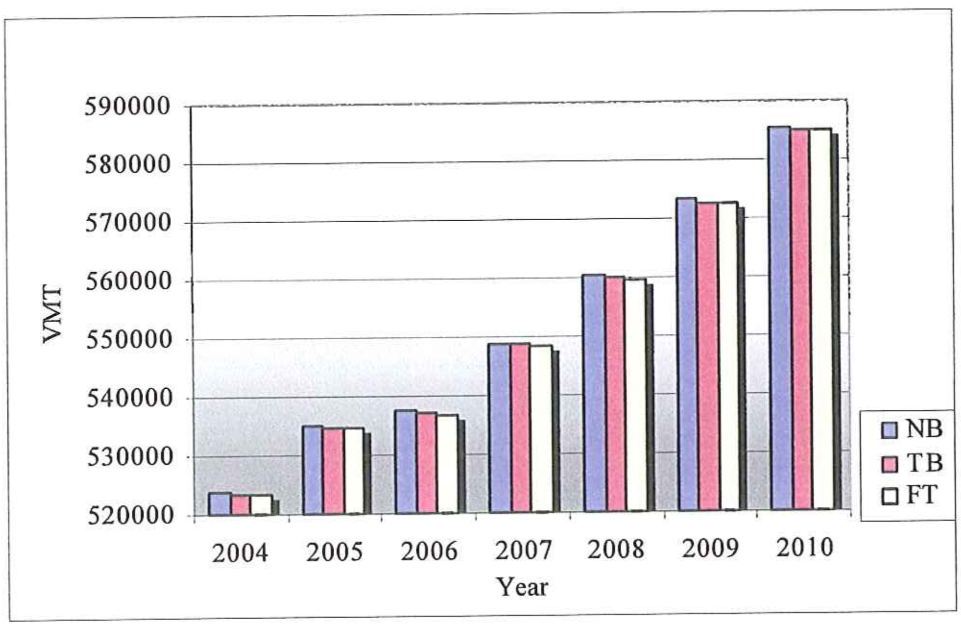


Figure 7.3 Project# 1,3&4-Vehicle Miles of Travel in PM peak period

The figures below are the VHD values for the AM, PM and daily periods for all three build scenarios from the years 2004-2010. Figures 7.4 and 7.5 show that FT construction has a significant savings in VHD over the NB and TB scenarios and the TB scenario has the highest VHD in absolute number. Figure 7.5 shows that there is a sharp increase in the VHD from 2005-2006 for TB and NB. The VHD values for FT are lower but the increase is steady. Figure 7.4 shows that the increase is steady for the TB scenario until 2008 but there is a sharp decrease for FT from 2005-2006. This shows that, overall, the PM peak period has a higher VHD.

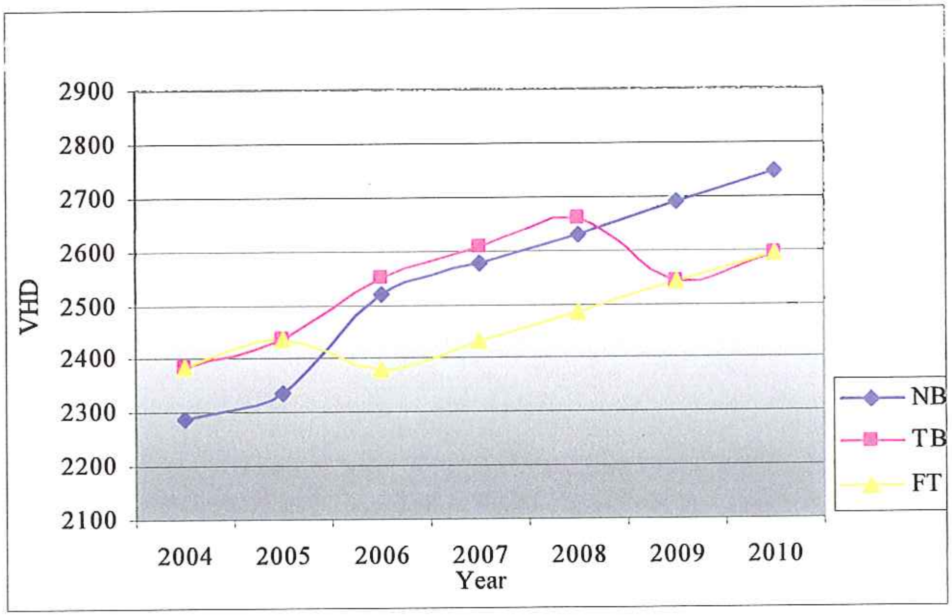


Figure 7.4 Project# 1,3&4-Vehicle Hours of Delay in AM peak period

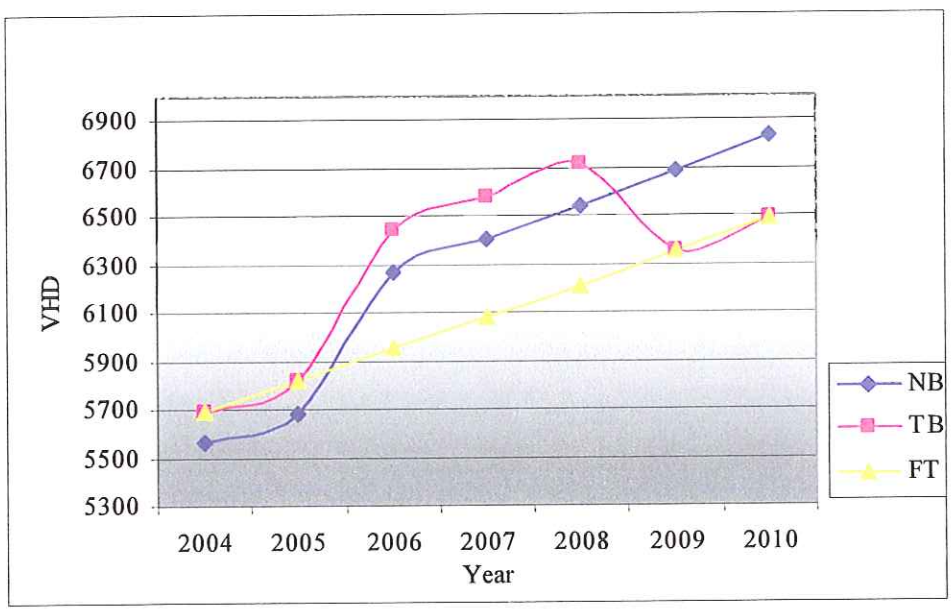


Figure 7.5 Project# 1,3&4-Vehicle hours of Delay in PM peak period

Figure 7.6 shows the daily VHD for all the build scenarios for all the simulation years. The FT scenario has a significant saving in VHD over the NB and TB scenarios. The travel time benefits that are obtained by the TB scenario after 2008 are obtained by the FT scenario after 2005. The variation in VHD for the FT scenario is much more gradual than the variation in VHD for the NB and TB scenarios.

The VMT and VHD trends for the three build scenarios lead to some important observations. It should be noted that the PM peak period has a higher VMT and VHD, so construction should be avoided during the PM peak periods. Also, it is seen that the construction scenarios do not have an impact on the VMT as it keeps increasing. Hence, it can be said the travel pattern will remain the same for the region. This indicates that 700 E is a major arterial and it is unlikely that the commuters will change their travel behavior.

Given all the facts it is evident that the delay savings are higher with the FT method and the benefits can be achieved in a shorter amount of time.

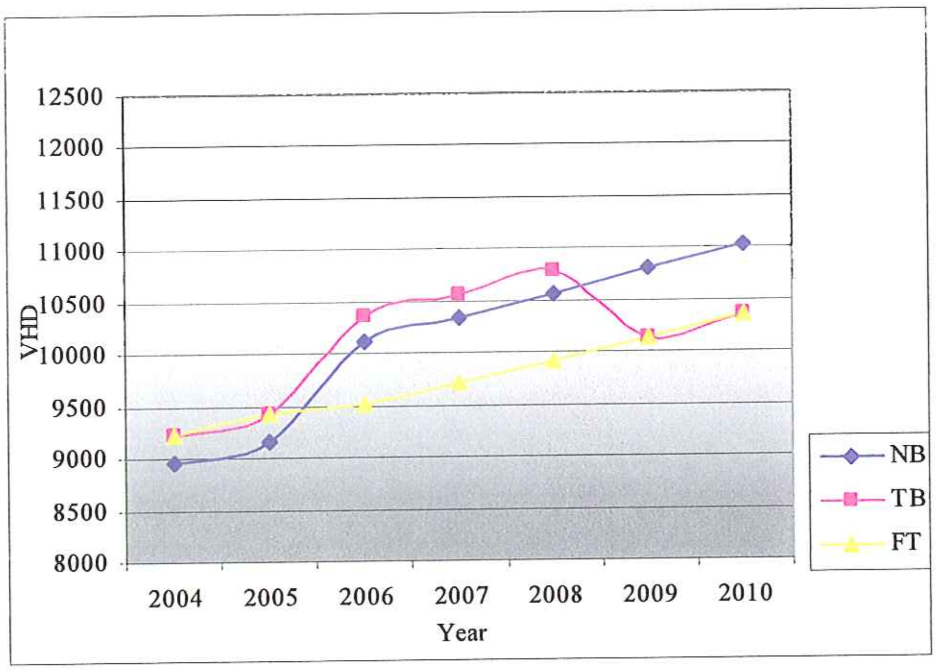


Figure 7.6 Project# 1, 3 & 4 - Daily Vehicle Hours of Delay

7.1.2 Project# 2 (7800 S Redwood Rd./Bangerter)

Figures 7.7 and 7.8 show the AM and PM peak VMT for the build scenarios during all simulation periods. It can be observed that the PM peak period has a higher VMT than the AM peak period and there is an increasing trend over the years. There is a marginal increase in VMT for the FT scenario in the AM peak than for NB and TB. There is an increase of 10.7% in the AM peak VMT and a 12.6% increase in the PM peak VMT over the years.

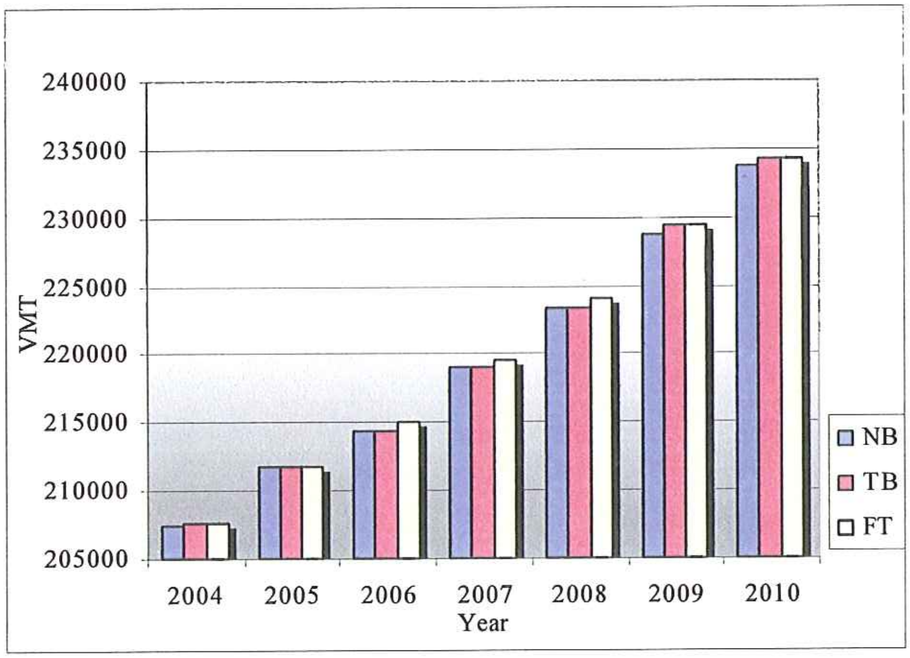


Figure 7.7 Project# 2-Vehicle Miles of Travel in AM peak period

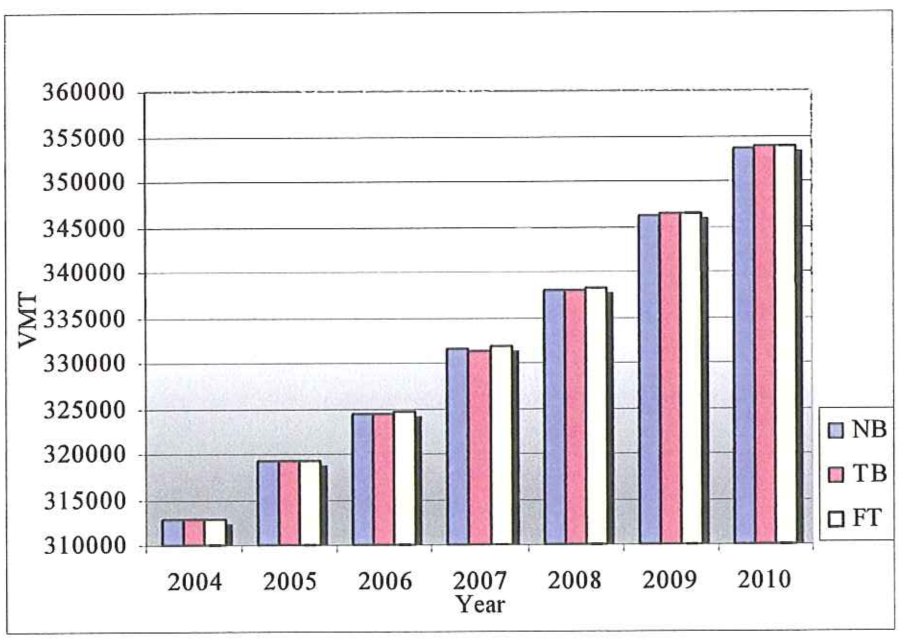


Figure 7.8 Project# 2-Vehicle Miles of Travel in PM peak period

Figure 7.9 shows the daily variation of VMT over the years for all three scenarios. It can be seen that the VMT increases over the years by 11.5% and the increase is almost constant for all the scenarios. The peak period variation also shows that the PM peak has a higher VMT than the AM peak.

There is marginal difference in the absolute value of VMT for all the build scenarios. At a couple of points the FT scenario shows a higher VMT than the other two scenarios. This shows that the travel demand increases marginally with improvement in the road network for the FT scenario.

A significant observation that can be made is that the daily VMT ,when compared to the AM or the PM peak, suggests that the non-peak VMT is much lower. Hence, the absolute difference in VMT is much lower.

An increasing VMT for all the scenarios suggests that the travel pattern for the region will not be drastically affected by construction activities. This suggests that 7800 S is a critical arterial that will keep inducing travel demand regardless of the network improvements. However there might be significant differences in the VHD values that will impact user delay, which will be seen in the subsequent sections.

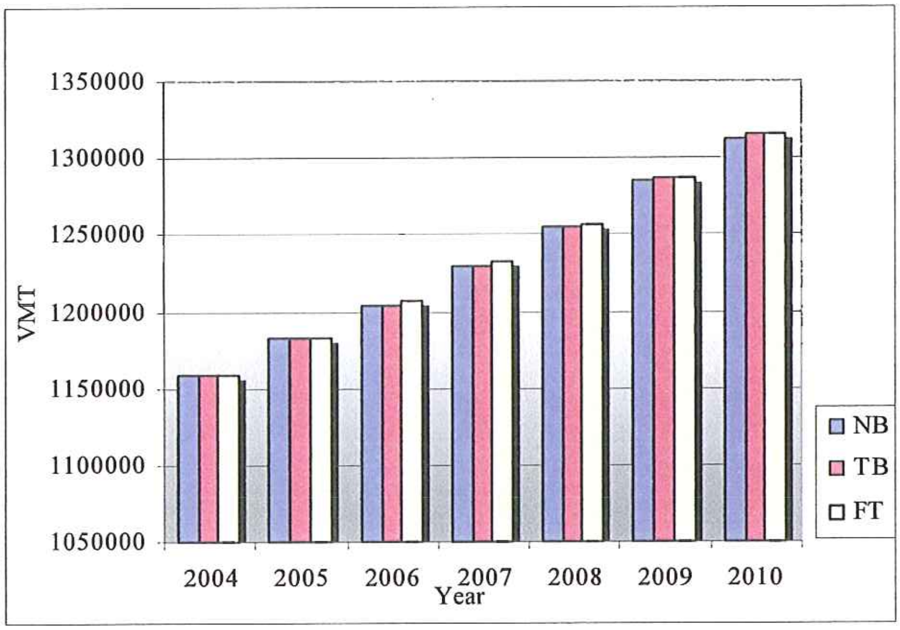


Figure 7.9 Project# 2-Vehicle miles of Travel (Daily)

Figures 7.10 and 7.11 show the VHD values for the AM and the PM peak periods. It can be observed that the PM peak period VHD is more than double that of the AM period. Also the variation in the NB and TB VHD for the AM peak is higher than the variation in the PM peak VHD. However, the FT VHD is significantly less than for the NB and TB scenarios. The slope of the curves for the FT in the AM and PM peak is similar, hence the percentage increase in VHD is the same for both scenarios. For the FT build scenario there is a 14.5% increase in AM peak VHD over the years and for the PM peak there is a 18.6% increase. There is a significant saving in delay for the FT scenario over NB and TB.

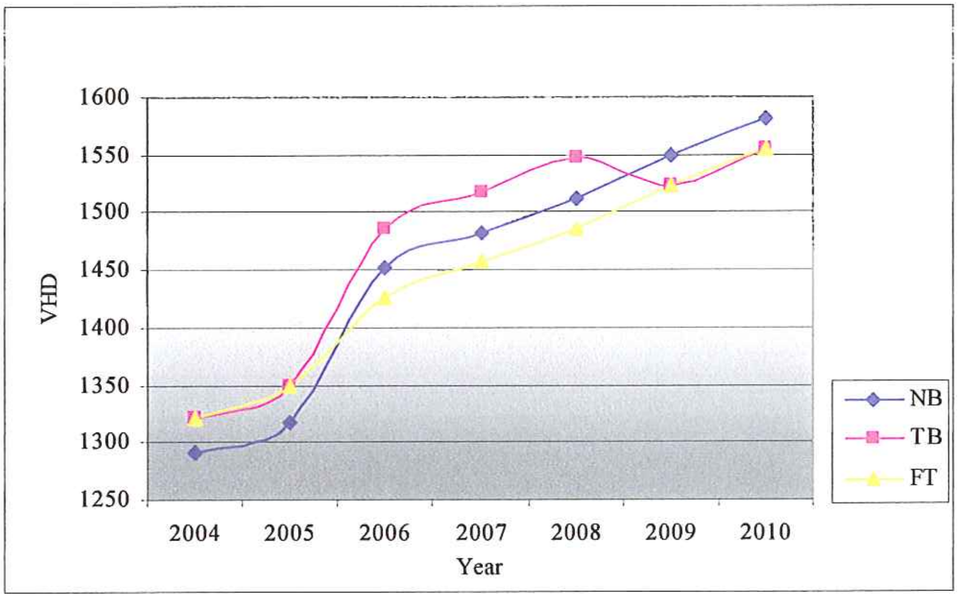


Figure 7.10 Project# 2-Vehicle hours of Delay in AM peak period

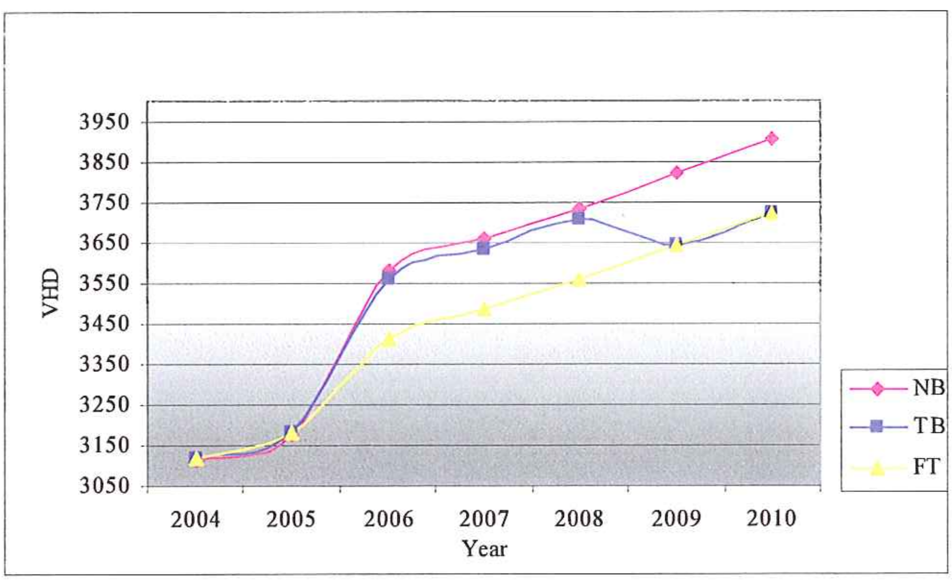


Figure 7.11 Project# 2-Vehicle hours of Delay in PM peak period

The daily VHD values as shown in Figure 7.12 indicate that the NB and TB scenarios will have the same VHD on the network over time. This tells us that this section of the roadway definitely demands capacity augmentation over the years to keep up with the increasing travel demand. The absolute increase in VHD for the FT scenario is very gradual but there is definately a significant saving in user delay over the NB and TB cases.

It can also be seen that the FT and TB scenarios initially have a higher VHD than the NB scenario, but later the rise in NB and TB is much sharper than the FT.

Proximity to the two major arterials, Redwood Rd. and Bangerter Hwy., might be one of the reasons for the increasing travel demand that causes an increase in the VHD value for the NB scenario equivalent to the TB scenario.

Given all the scenarios, it is evident that the FT method will have a significant saving in delay and the savings are much higher than for the other two scenarios. Also, the PM peak is more critical than the AM peak. Hence, it is recommended that the construction be done after the PM peak, but it can continue until dawn since the AM peak is less intense.

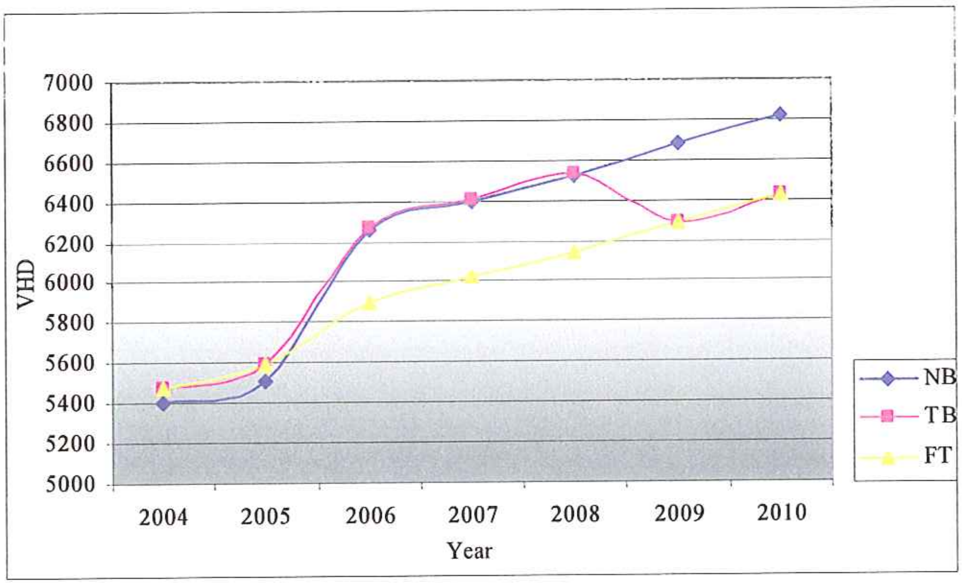


Figure 7.12 Project# 2-Daily Vehicle hours of Delay

7.1.3 Project# 5 (I-215 bridge-reconstruction)

Figures 7.13 and 7.14 show that the VMT for the AM and PM peak periods are almost the same for all the build scenarios and there is an increase in the VMT over the years. The VMT increased by approximately 12.1% over the years for both the peak periods. Unlike all the other projects there was not a significant difference in the VMT for the AM and PM peak periods. This can be attributed to the fact that the project is on an interstate and the travel pattern on the interstate during the AM and PM periods are not likely to change significantly.

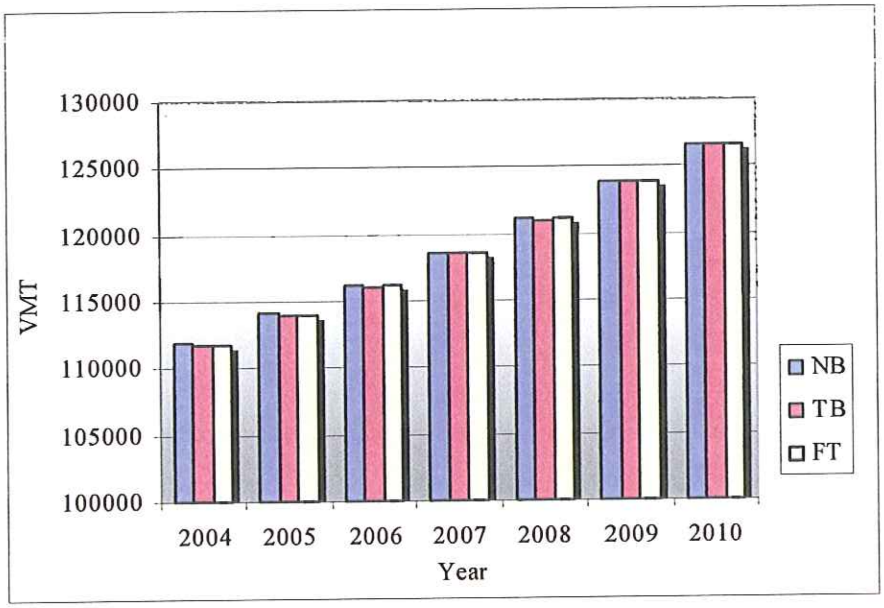


Figure 7.13 Project# 5-Vehicle Miles of Travel in AM peak period

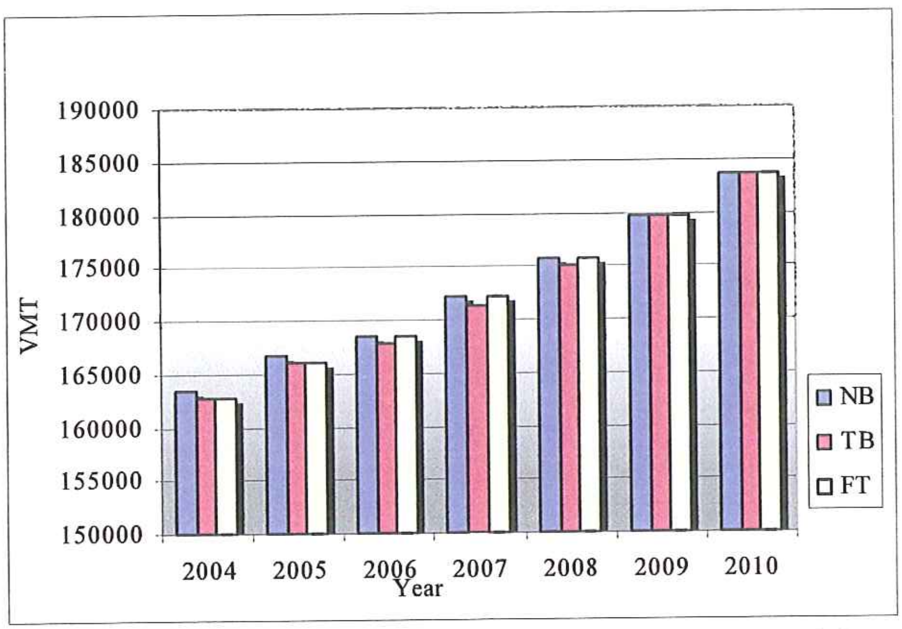


Figure 7.14 Project# 5-Vehicle Miles of Travel in PM peak period

Figure 7.15 shows the daily VMT for all the project scenarios for all time periods. It can be seen that the daily VMT shows an increasing trend over the years and there is an increase of 11.2% from the year 2004 until 2010. The NB scenario has a marginally higher VMT until the year 2008 and thereafter all the scenarios have almost the same VMT.

In terms of absolute numbers, the daily VMT in 2004 is observed as 630000; for the year 2008 it is 680000 and for the year 2010 it is 710000.

After comparing the AM and PM peak VMT with the daily values it can be concluded that there is a significant VMT during the off peak periods as well. This suggests that the interstate is used extensively during the off peak periods as well.

A stronger conclusion can be reached when the VHD is also taken into account and compared with the VMT. This is discussed in the following sections.

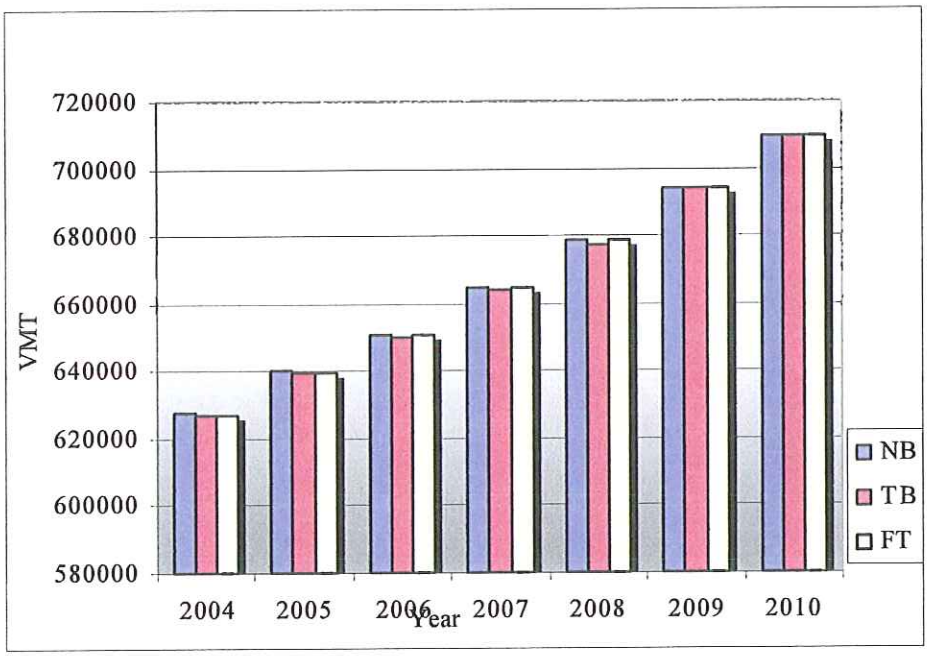


Figure 7.15 Project# 5- Vehicle Miles of Travel (Daily)

Figures 7.16 and 7.17 show the VHD for the AM and the PM peak periods for this project area and it can be seen that the absolute VHD is much lower when compared to the VHD for the previous projects. Also it can be seen that there is not much of a difference in the range of VHD for the peak periods. This suggests that the interstate is used by a similar amount of traffic for both peak periods. However, it is interesting to see that for the AM peak there is no change in the VHD values for all three build scenarios. There is a sharp increase in VHD from 2004 until 2006 and then the increase is more gradual. There is an increase of 27.7% in the AM peak VHD for FT and a marginal increase of approximately 2% for the PM peak FT method. For the PM peak the VHD for NB is almost the same from 2006 until 2010.

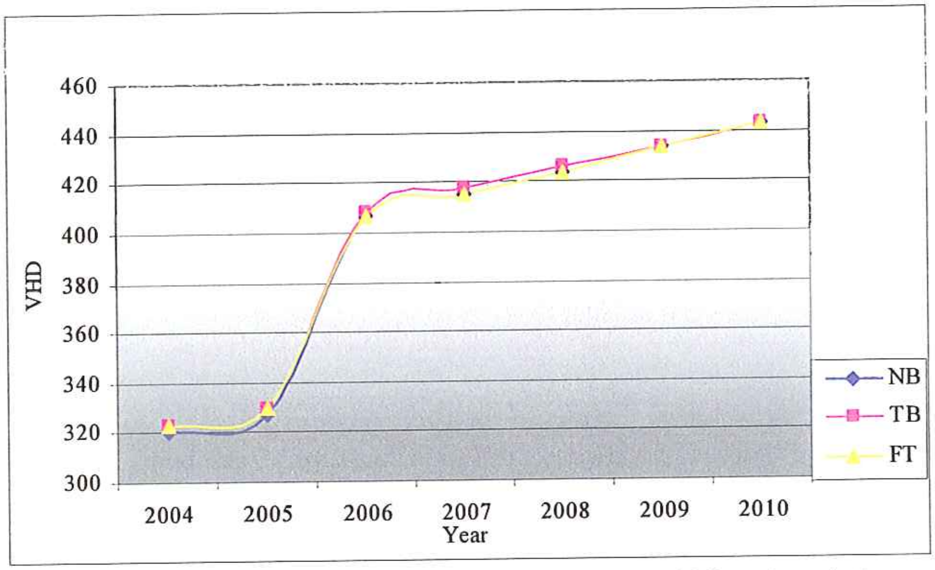


Figure 7.16 Project# 5-Vehicle Hours of Delay in AM peak period

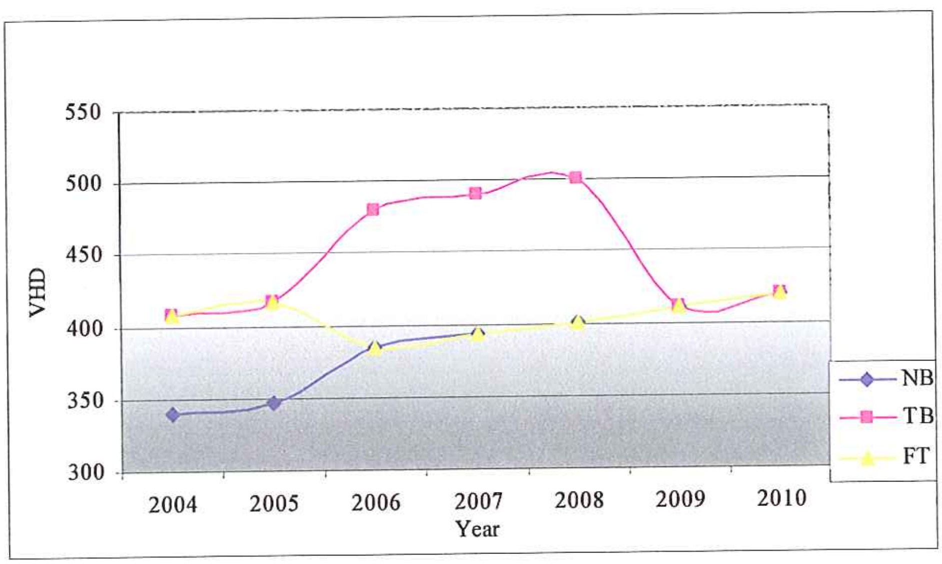


Figure 7.17 Project# 5-Vehicle Miles of Travel in PM peak period

The daily VHD values suggest that the delay is higher for FT and TB than for NB from 2004 until 2006. After 2006 the FT and NB scenarios have similar delay values but the TB scenario has a significantly higher delay.

With the FT method the increase in VHD is 16.2% from 2004 until 2008. In terms of absolute value, however, the VHD for this project is significantly lower than for the other two projects.

Given all the scenarios it is evident that the FT method will have a significant saving in delay and the savings are much higher than the other two scenarios. Nevertheless, this project will have a significantly lower impact than the other two projects in terms of absolute VHD numbers. Since there is not much difference in the AM and PM peak VMT and VHD values, it is recommended that the construction be carried out during the nighttime.

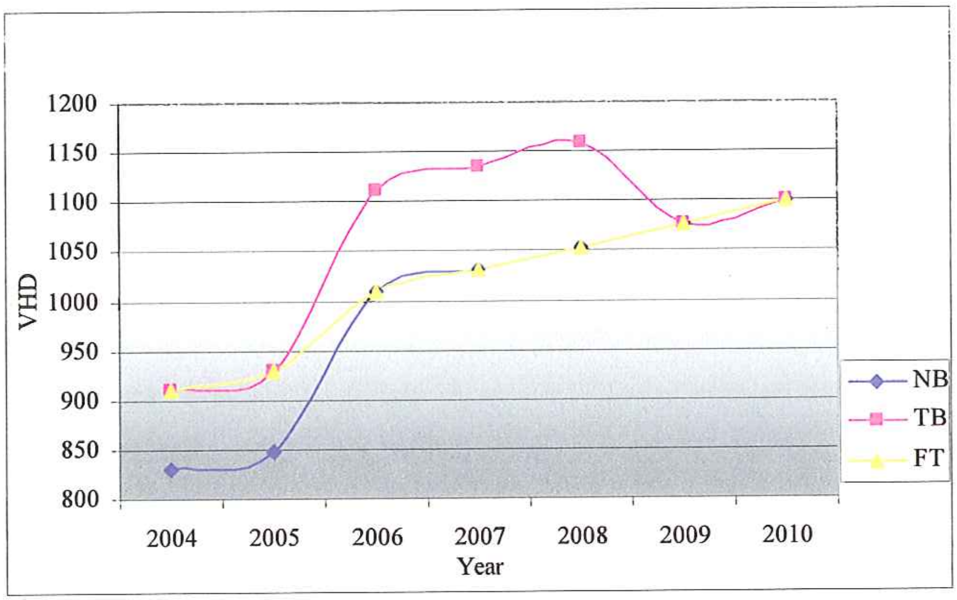


Figure 7.18 Project# 5-Daily Vehicle hours of Delay

7.2 Second Delay (VHD in sec/VMT)

Second delay is a very good measure of the network performance regardless of the total VMT on the network. This MOE is used to directly measure the impact of the project for all three build scenarios in this study. Table 7.1 shows the second delay for all the analysis areas comprising all the projects for 2004 and 2008. The years were chosen keeping in mind the horizon year of the STIP projects and the start time.

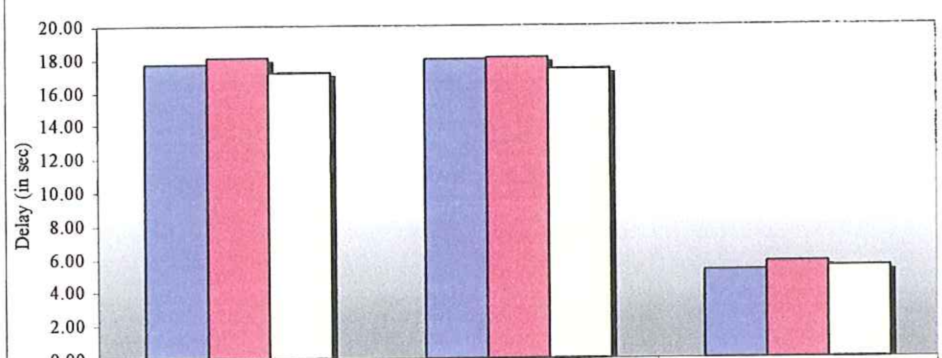
Table 7.1 Second Delay for all Analysis Areas

	700 E 106th South (project# 1,3&4)			7800 S – Redwood/Bangerter (project# 2)			I-215 Bridge Re-const. (project# 5)		
	NB	TB	FT	NB	TB	FT	NB	TB	FT
2004	16.68	17.19	17.19	16.77	17.02	17.02	4.76	5.23	5.23
2008	18.32	18.73	17.21	18.72	18.76	17.60	5.59	6.16	5.59
Average	17.66	18.11	17.20	17.94	18.07	17.37	5.26	5.79	5.44

It can be observed from the table that the lowest second delay is observed for the I-215 project than the other two areas for all the build scenarios. There is a difference of 0.91 average seconds per vehicle miles of travel from NB to FT for the 700 E project. For the 7800 S project it is of the order of 0.7 seconds.

For the 700 E project there is an increase of 1.54 seconds for TB from 2004 to 2008 but for FT it is 0.2 seconds. Also FT has the lowest average second delay over TB and NB. This shows that with the TB construction method there will be a higher impact on the network for a longer period of time than for the FT method.

For the 7800 S project it can be seen that there is an increase of 1.74 seconds with TB from 2004 to 2008, but for FT it is 0.58 seconds. Again, FT will have a lower impact on the network than the TB method for a longer period of time.



	700 E 106th South	7800 S	I-215 Bridge Re-Cosnt.
NB	17.66	17.94	5.26
TB	18.11	18.07	5.79
FT	17.20	17.37	5.44

Figure 7.19 Average Second Delay (VHD in sec/VMT)

Figure 7.19 shows that the second delay for the I-215 project is the lowest and for 700 E it is marginally higher than 7800 S for all the build scenarios. Also, the FT method has the lowest value when compared to the NB and TB methods for all three project areas.

From this it can be concluded that when the three projects are compared the FT method will save have significant savings in user delay. It can also be concluded that the I-215 project will have a lower impact than the other two. This can be attributed to the fact that it is an interstate and the severity of the project is much lower than the other two. 700 E is a major arterial and hence the second delay is higher. The same is true for 7800 S since it is in the proximity of two major arterials, Redwood Rd. and Bangerter Hwy.

7.3 Cost Implication (delay cost due to construction VHD)

It is difficult to convert the travel impact into monetary values. The research on conversion of delay into cost terms is also very sparse. However one of the methods to convert vehicular delay due to construction into monetary terms is by multiplying the VHD by a dollar value that represents delay per hour. For this study a methodology proposed by the National Co-operative Highway Research's (NCHRP) report 358 entitled "Recommended Practices for Use of Traffic Barrier and Control Treatments for Restricted Work Zones" has been used to convert the delay in terms of user cost. The proposed estimate of the value of time of $13 per vehicle hour of delay is used and is multiplied by the daily VHD for each analysis area to obtain the dollar value. This cost is the "delay cost" due to construction delay. Figures 7.20, 7.21 and 7.23 represent the estimated delay cost for each of the analysis areas.

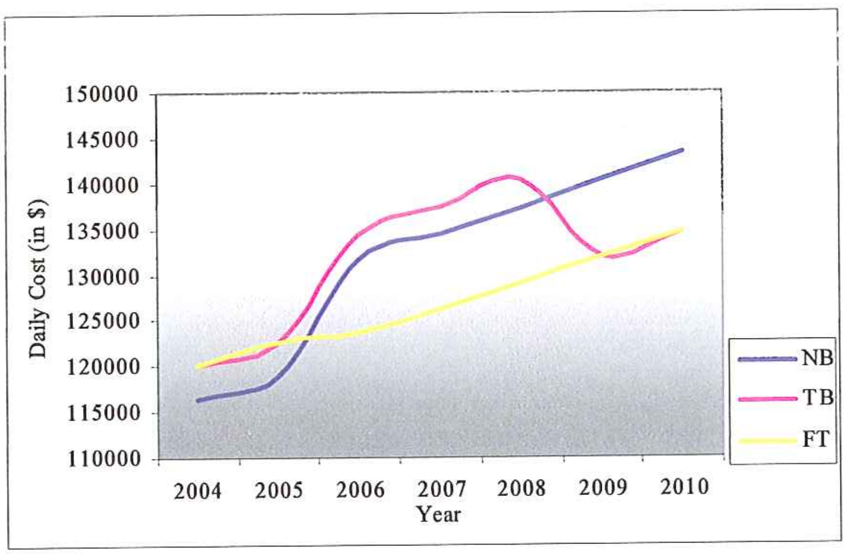


Figure 7.20 Delay Cost estimate for Project# 1,3&4 – 700E, State St, 106th S

Figure 7.20 shows that there is a significant saving in delay cost for the FT method over the TB method. It should also be noted that the benefits obtained by the TB method catch up with the FT method only after construction ends in 2008. The FT daily delay cost benefit is $15,000 over TB and approximately $13,000 over NB. So it is recommended that the FT method be adopted for the 700 E project. There is a steep rise in the delay cost for the NB and TB scenarios but the FT scenario has a gradual slope.

Figure 7.21 shows that the NB and TB scenarios for the 7800 S project have a similar daily delay cost from 2006 until 2008. Later, the TB scenario reaps the benefits and the cost becomes equivalent to FT. But, the FT scenario has a much lower daily delay cost than both the scenarios and the delay cost benefits are much higher. The benefits in daily delay cost for FT when compared to NB and TB is approximately $10,000. There is a gradual increase in the cost for FT from 2006 until 2010, but the increase is gradual.

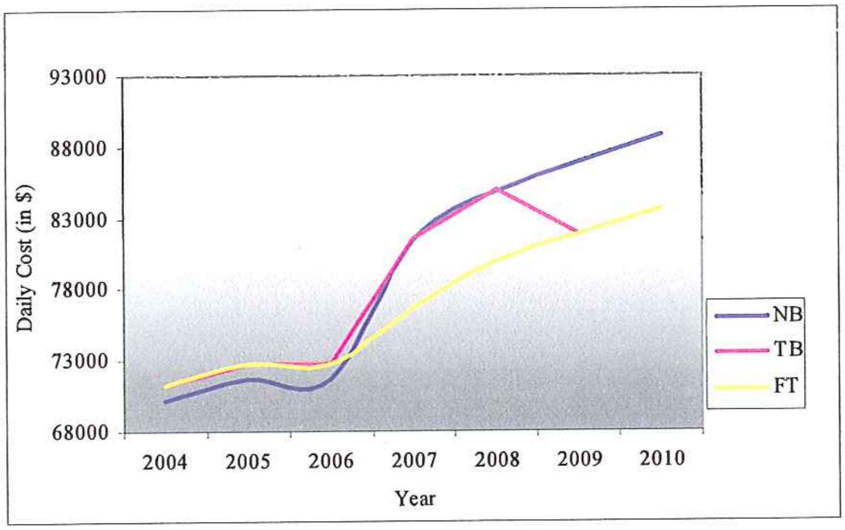


Figure 7.21 Delay Cost estimate for Project# 2– 7800S Redwood/Bangerter

Figure 7.22 gives the daily delay cost estimate for the I-215 bridge-reconstruction project. It can be seen that the daily delay benefits of FT vs. TB is approximately $1000. However, it is interesting to observe that there is no difference in FT and NB after 2006. Compared to the other four projects the daily delay cost benefits are much lower for I-215. This is due to the fact the VHD for this project, as a result of the construction, is also significantly less than the other projects.

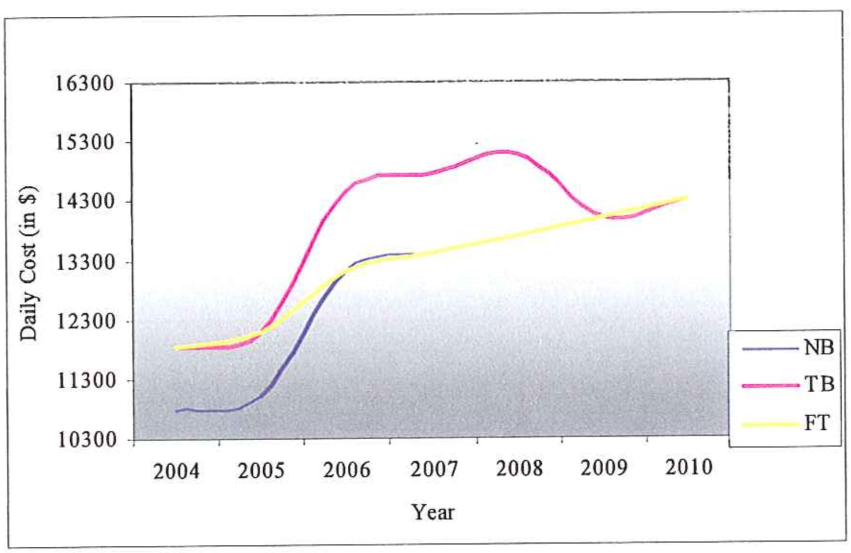


Figure 7.22 Delay Cost estimate for Project# 5– I-215 Bridge-reconstruction

Table 7.2 is a comparison of the estimated cost of the projects and the saving in delay cost during the period of construction. It can be seen that the highest benefits are obtained for the 700 E project followed by the 7800 S and I-215 projects.

If the FT method is used for the 700 E project, there will be a saving of $12.96 million in terms of delay; $5.4 million for 7800 S and $2 million for I-215. Looking at these results, it can be said that it is highly recommended that the 700 E project be done with the FT method, but the same cannot be said for the 7800 S project since the savings are comparatively less. Also, since 700 E is a major arterial, it is imperative to reduce the delay on the network due to construction so the FT method should be used.

Table 7.2 Saving from FT compared to TB for the Project Duration

	Project Cost	Delay Cost Saving
700 E 106th South	$33 Million	$12.96 Million
7800 S (Redwood/Bangerter)	$21.3 Million	$5.4 Million
I-215 Bridge Re-const.	$4.35 Million	$2 Million

The delay cost amounts to 1/3 of the total project cost for the 700 E project and 1/4 for the 7800 S project. Although comparing the delay cost with the estimated project cost might not be a very accurate method of comparison, it does give a ballpark figure that would help to decide which method of construction should be used.

8. CONCLUSIONS

The design build method definitely has higher benefits in terms of reduced delay and delay cost than the traditional build technique. However the extent of this benefit can vary depending on many factors, therefore, there are varying levels of travel time and delay cost savings for the various projects analyzed as a part of this study. Use of a "transportation planning model" like VISUM for this study has definitely proved to be beneficial for travel demand forecasting for future years. For road construction projects that are a part of long range plans like STIP, it is necessary to model the impact for a network. Transportation planning models are the most appropriate for this task.

For this study it was seen that, of the five projects selected, the impact of construction varied depending on the type of project, the extent of the project, the existing and future travel demand, and the type of construction method used. The PM peak period for all the projects was observed to be critical and so construction during the PM peak is not recommended. Also, in terms of travel and cost impact, project #5 (I-215) reconstruction had the lowest impact over the other four projects.

Some significant conclusions that can be drawn about the 700 E, State St, 106th S project (#1, 3 & 4) are:

- The VHD is the highest for these projects
- The PM peak period is critical since the VHD and VMT are higher and will have a significant impact on construction
- The average second delay is lowest for FT but is higher than the other projects
- There is a saving of $13 million in delay cost for FT over TB

Some significant conclusions about the 7800 S – Redwood/Bangeter project (# 2) are:

- The VHD for NB and TB are almost equal after 2005, which shows that capacity augmentation is needed in the long run due to increasing travel demand
- There is a saving in delay cost with the FT method
- Due to higher VHD and VMT values during the PM peak, construction is not desirable during this period
- There are fewer trip changes for the TB and NB scenario because, in spite of construction, the VHD values are almost equal
- There is a saving of $5.4 million for FT over TB

Some significant conclusions about the I-215 project (#5) are:

- The VHD is the lowest in absolute number compared to the other projects
- The AM and PM peak VHD is almost the same in terms of absolute number
- The delay seconds are the lowest compared to the other projects
- It has the least impact anticipated due to the construction activity, but off peak construction is desirable
- There is a saving of $2 million if FT is used over TB

9. RECOMMENDATIONS

The following recommendations were made after analyzing all the projects:

- The FT method is recommended for all three projects since the saving in delay cost due to construction is much higher than the TB method
- Construction should be avoided during the PM peak period as it will cause higher network delays
- Construction should be done during the late evening through dawn to minimize impact due to delay
- The 700 E project will have the highest impact in terms of VHD and seconds delay compared to all the other projects
- The I-215 project will have the least impact on delay, however construction is recommended only during the off peak hours
- The savings in delay cost is the highest for the 700 E project, therefore, the FT method should definitely be considered
- For the 7800 S project the delay cost savings is ¼ compared to the total project cost, so both the TB and FT methods are desirable

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APPENDIX

VMT Project No. 1,3&4 - at 700E and State St.				
		NB	TB	FT
2004	AM	322444.35	323073.62	323073.62
	PM	523610.31	523419.67	523419.67
	MD	652559.08	652776.78	652776.78
	EV	434663.72	434664.7	434664.7
	DAILY	1933277	1933935	1933935
2005	AM	329360.93	330003.69	330003.69
	PM	534841.99	534647.26	534647.26
	MD	666556.77	666779.14	666779.14
	EV	443987.46	443988.46	443988.46
	DAILY	1974747	1975419	1975419
2006	AM	330233.99	330370.84	330348.46
	PM	537323.17	537094.08	536618.59
	MD	673560.19	673774.7	673388.6
	EV	448661.18	448661.18	448661.18
	DAILY	1989779	1989901	1989017
2007	AM	337317.66	337457.45	337434.58
	PM	548849	548615	548129.31
	MD	688008.37	688227.47	687833.09
	EV	458285.17	458285.17	458285.17
	DAILY	2032460	2032585	2031682
2008	AM	344401.33	344544.05	344520.71
	PM	560374.83	560135.91	559640.02
	MD	702456.54	702680.25	702277.59
	EV	467909.16	467909.16	467909.16
	DAILY	2075142	2075269	2074347
2009	AM	352359.66	352481.8	352481.8
	PM	573323.82	572572.04	572572.04
	MD	718688.72	718505.63	718505.63
	EV	478721.48	478721.48	478721.48
	DAILY	2123094	2122281	2122281
2010	AM	359917.94	360042.7	360042.7
	PM	585621.88	584853.97	584853.97
	MD	734104.93	733917.91	733917.91
	EV	488990.27	488990.27	488990.27
	DAILY	2168635	2167805	2167805

VHD Project No. 1,3&4 - at 700E and State St.				
		NB	TB	FT
2004	AM	2286.774	2384.517	2384.517
	PM	5562.267	5695.124	5695.124
	MD	1106.83	1150.105	1150.105
	EV	1.489712	4.405772	4.405772
	DAILY	8957.36	9234.15	9234.15
2005	AM	2335.827	2435.666	2435.666
	PM	5681.58	5817.288	5817.288
	MD	1130.572	1174.775	1174.775
	EV	1.521667	4.500278	4.500278
	DAILY	9149.5	9432.23	9432.23
2006	AM	2520.575	2550.636	2380.97
	PM	6267.398	6439.319	5957.629
	MD	1334.057	1356.074	1170.621
	EV	1.541109	4.516997	1.541109
	DAILY	10123.6	10350.5	9510.76
2007	AM	2574.643	2605.349	2432.043
	PM	6401.836	6577.445	6085.423
	MD	1362.673	1385.162	1195.732
	EV	1.574167	4.613889	1.574167
	DAILY	10340.7	10572.6	9714.77
2008	AM	2628.71	2660.061	2483.116
	PM	6536.275	6715.571	6213.217
	MD	1391.289	1414.251	1220.842
	EV	1.607224	4.710781	1.607224
	DAILY	10557.9	10794.6	9918.78
2009	AM	2689.454	2540.495	2540.495
	PM	6687.313	6356.791	6356.791
	MD	1423.439	1249.053	1249.053
	EV	1.644363	1.644363	1.644363
	DAILY	10801.9	10148	10148
2010	AM	2747.144	2594.99	2594.99
	PM	6830.759	6493.147	6493.147
	MD	1453.972	1275.846	1275.846
	EV	1.679636	1.679636	1.679636
	DAILY	11033.6	10365.7	10365.7

VMT Project No. 2 - at Redwood and Bangarter					VHD Project No. 2 - at Redwood and Bangarter				
		NB	TB	FT			NB	TB	FT
2004	AM	207451.6	207572.2	207572.2	2004	AM	1290.783	1321.805	1321.805
	PM	312791.1	312825.6	312825.6		PM	3115.012	3119.63	3119.63
	MD	401846.9	401601.4	401601.4		MD	993.6862	1038.376	1038.376
	EV	236957.4	236957.4	236957.4		EV	0.551951	0.898878	0.898878
	DAILY	1159047	1158957	1158957		DAILY	5400.03	5480.71	5480.71
2005	AM	211685.3	211808.4	211808.4	2005	AM	1317.125	1348.781	1348.781
	PM	319174.6	319209.8	319209.8		PM	3178.584	3183.296	3183.296
	MD	410047.9	409797.3	409797.3		MD	1013.966	1059.568	1059.568
	EV	241793.3	241793.3	241793.3		EV	0.563215	0.917222	0.917222
	DAILY	1182701	1182609	1182609		DAILY	5510.24	5592.56	5592.56
2006	AM	214420.2	214406.3	215025	2006	AM	1451.427	1485.181	1426.736
	PM	324459.4	324349.5	324729.4		PM	3582.343	3558.05	3414.019
	MD	420506.9	420476.2	421975.5		MD	1227.727	1230.282	1057.222
	EV	244651.9	244651.9	244651.9		EV	0.904694	0.926243	0.926243
	DAILY	1204038	1203884	1206382		DAILY	6262.4	6274.44	5898.9
2007	AM	219019.6	219005.4	219637.3	2007	AM	1482.56	1517.038	1457.341
	PM	331419.2	331307	331695		PM	3659.186	3634.372	3487.251
	MD	429527	429495.6	431027		MD	1254.063	1256.672	1079.899
	EV	249899.8	249899.8	249899.8		EV	0.9241	0.946111	0.946111
	DAILY	1229866	1229708	1232259		DAILY	6396.73	6409.03	6025.44
2008	AM	223400	223385.5	224030.1	2008	AM	1512.211	1547.379	1486.487
	PM	338047.6	337933.1	338328.9		PM	3732.37	3707.059	3556.996
	MD	438117.5	438085.5	439647.6		MD	1279.144	1281.805	1101.497
	EV	254897.8	254897.8	254897.8		EV	0.942582	0.965033	0.965033
	DAILY	1254463	1254302	1256904		DAILY	6524.67	6537.21	6145.95
2009	AM	228786.3	229431.6	229431.6	2009	AM	1548.672	1522.328	1522.328
	PM	346198.1	346486.3	346486.3		PM	3822.36	3642.758	3642.758
	MD	448680.9	450247.8	450247.8		MD	1309.985	1128.055	1128.055
	EV	261043.6	261043.6	261043.6		EV	0.965308	0.988301	0.988301
	DAILY	1284709	1287209	1287209		DAILY	6681.98	6294.13	6294.13
2010	AM	233693.9	234353	234353	2010	AM	1581.892	1554.982	1554.982
	PM	353624.3	353918.6	353918.6		PM	3904.351	3720.897	3720.897
	MD	458305.3	459905.8	459905.8		MD	1338.085	1152.253	1152.253
	EV	266643.1	266643.1	266643.1		EV	0.986015	1.009501	1.009501
	DAILY	1312267	1314821	1314821		DAILY	6825.31	6429.14	6429.14

VMT Project No. 5 - at I-215 'Lego Bridge'					VHD Project No. 5 - at I-215 'Lego Bridge'				
		NB	TB	FT			NB	TB	FT
2004	AM	111853.8	111772.9	111772.9	2004	AM	320.7235	323.029	323.029
	PM	163314	162756.3	162756.3		PM	339.6476	408.1011	408.1011
	MD	216507.6	216358.9	216358.9		MD	168.6869	178.4498	178.4498
	EV	135960.6	135898	135898		EV	0.895611	0.895611	0.895611
	DAILY	627636	626786	626786		DAILY	829.954	910.476	910.476
2005	AM	114136.6	114054	114054	2005	AM	327.2689	329.6214	329.6214
	PM	166647	166077.9	166077.9		PM	346.5792	416.4297	416.4297
	MD	220926.1	220774.3	220774.3		MD	172.1294	182.0917	182.0917
	EV	138735.3	138671.4	138671.4		EV	0.913889	0.913889	0.913889
	DAILY	640445	639578	639578		DAILY	846.891	929.057	929.057
2006	AM	116123.4	116030.5	116123.4	2006	AM	406.2532	408.6618	406.2532
	PM	168484.4	167795.5	168484.4		PM	384.7587	479.8729	384.7587
	MD	225590.5	225394.5	225590.5		MD	217.908	222.3002	217.908
	EV	140587.1	140522.7	140587.1		EV	0.936305	0.936305	0.936305
	DAILY	650785	649743	650785		DAILY	1009.86	1111.77	1009.86
2007	AM	118614.3	118519.4	118614.3	2007	AM	414.9675	417.4278	414.9675
	PM	172098.5	171394.8	172098.5		PM	393.0119	490.1664	393.0119
	MD	230429.6	230229.3	230429.6		MD	222.5822	227.0686	222.5822
	EV	143602.8	143537	143602.8		EV	0.956389	0.956389	0.956389
	DAILY	664745	663680	664745		DAILY	1031.52	1135.62	1031.52
2008	AM	121105.2	121008.3	121105.2	2008	AM	423.6818	426.1938	423.6818
	PM	175712.6	174994	175712.6		PM	401.2652	500.4599	401.2652
	MD	235268.6	235064.1	235268.6		MD	227.2564	231.8371	227.2564
	EV	146618.4	146551.3	146618.4		EV	0.976473	0.976473	0.976473
	DAILY	678705	677618	678705		DAILY	1053.18	1159.47	1053.18
2009	AM	123903.7	123903.7	123903.7	2009	AM	433.4721	433.4721	433.4721
	PM	179772.9	179772.9	179772.9		PM	410.5375	410.5375	410.5375
	MD	240705.1	240705.1	240705.1		MD	232.5078	232.5078	232.5078
	EV	150006.4	150006.4	150006.4		EV	0.999037	0.999037	0.999037
	Daily	694388	694388	694388		Daily	1077.52	1077.52	1077.52
2010	AM	126561.5	126561.5	126561.5	2010	AM	442.7703	442.7703	442.7703
	PM	183629.1	183629.1	183629.1		PM	419.3437	419.3437	419.3437
	MD	245868.3	245868.3	245868.3		MD	237.4952	237.4952	237.4952
	EV	153224.2	153224.2	153224.2		EV	1.020467	1.020467	1.020467
	DAILY	709283	709283	709283		DAILY	1100.63	1100.63	1100.63

Exhibit "B"

Utah Department of Transportation

Memorandum

DATE: February 8, 2005

TO: Deloy Dye, P.E.

FROM: Brandon Squire, P.E. BS
Region Two Resident Engineer

SUBJECT: Project *NH-BHF-215-9(112)14

The average time to construct the new widening of the bridges at Redwood, 5400 South, and 4700 South was approximately 21 weeks. This time is from when they started to excavate for the piles and footing to when the deck was cured and the polymer overlay was placed. This time does not include the structural steel painting. Also, these bridge widenings were delayed by approximately 4-6 weeks due to a national domestic steel shortage that affected the delivery of the steel girders to the project. The rehabilitation of the existing bridge decks took place after the new bridge widenings were complete. The rehabilitation work was done sporadically during a 6-week window while the PCCP was being placed. In my estimation, if the deck rehabilitation was on the critical path, it would have taken approximately 8 10-hours shifts with one crew for each bridge to remove the asphalt, remove the membrane, pothole patch the deck, prepare the deck for the polymer overlay, and place the polymer overlay. This is assuming about 40% of the deck needed pothole patching. We also performed some substructure rehabilitation and some seismic upgrades to the exiting bridges. This work was done sporadically throughout the project.

I hope this is the information that you were looking for. If you need any further info, please let me know.